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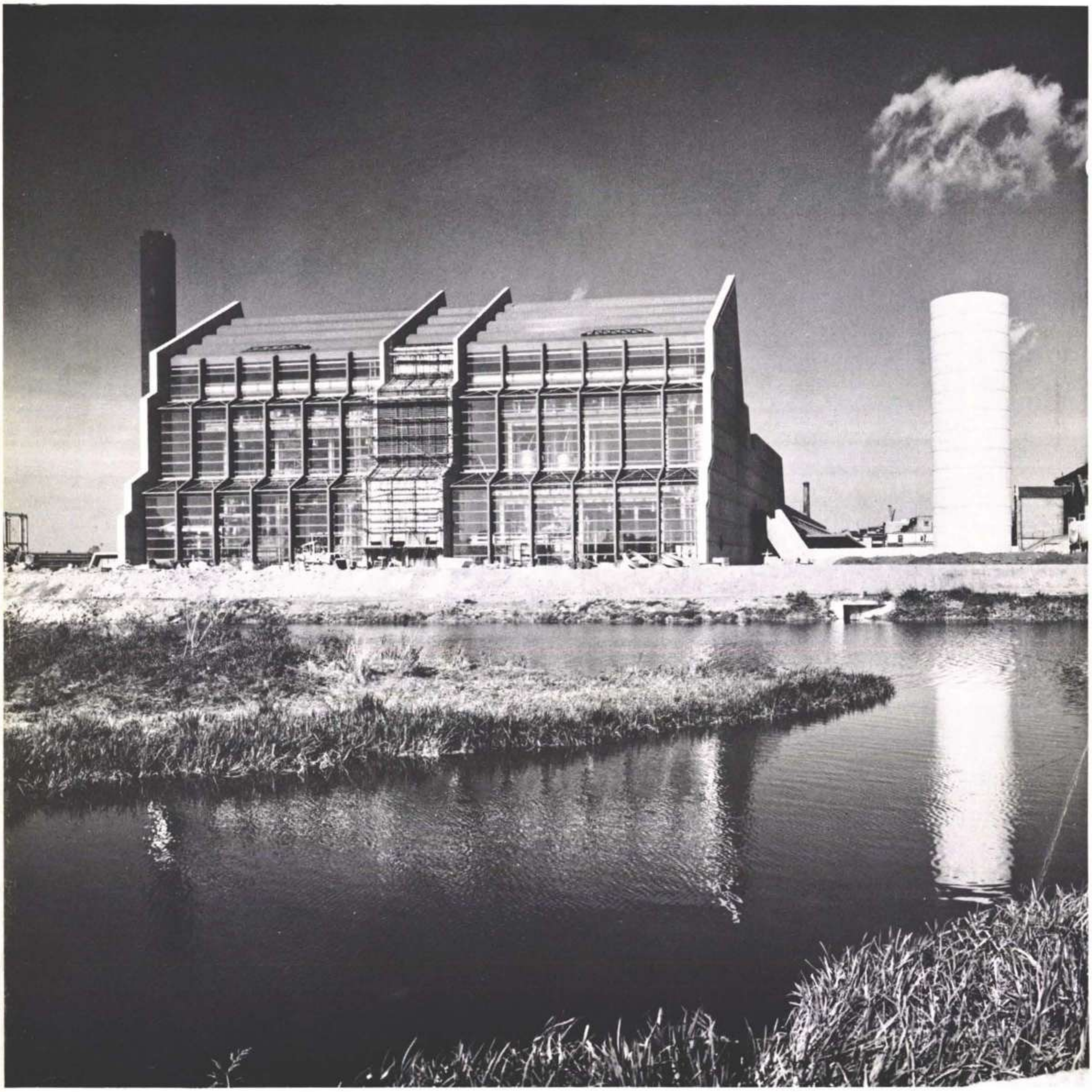

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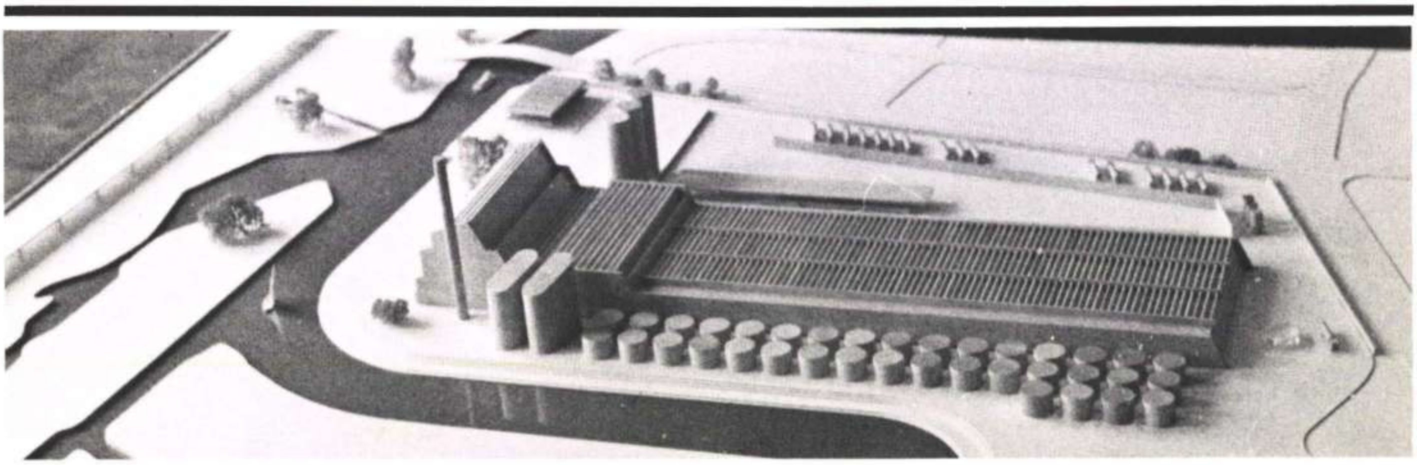
Front and back covers: Carlsberg Brewery, general view and east flank wall of the brewhouse (Photos: Colin Westwood)



Above: Model showing Phases 1 & 2

Carlsberg Brewery Northampton

Building Engineering Division - Group 3

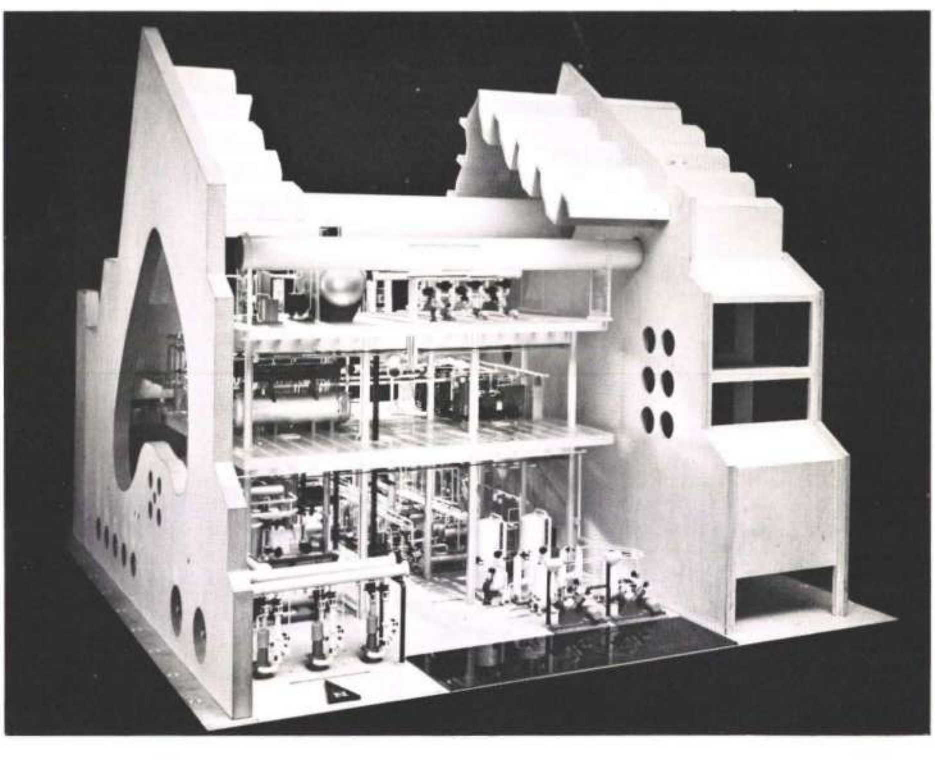
Introduction

In the autumn of 1970 we were appointed by the newly formed Carlsberg Brewery Ltd. to design the civil and structural engineering work and the mechanical and electrical utilities for a new £15m. Carlsberg Brewery in Northampton. In addition we were appointed to manage the whole of the project including the provision of quantity surveying and cost control, the latter, however, being only for work designed by ourselves.

The design of the process equipment was undertaken by Carlsberg's own design team, but the co-ordination and programming of their design was part of our management responsibility.

Knud Munk, a Danish architect, was appointed and the brief prepared by the client required the design of the brewery to express the best in modern Danish architecture. A very high standard of building finishes was required and the mechanical and electrical services had to be integrated. This was coupled with the

Below: Model of energy centre
(Photo: John Maltby Ltd.)



client's demands for a high hygienic quality, particularly in the process areas. In addition to a request for a high standard, the client required that the planning, design, construction and commissioning of this large and complex £15m. brewery; situated on a very restricted site; be carried out as quickly as possible. The aim was set high, namely to achieve the first brew by 1 April 1973. In other words, we had the task of dealing with three conflicting objectives; high quality, low cost and minimum construction time.

It soon became obvious to us that this project did not lend itself for a normal contractual set-up with a main contractor and as part of our management proposal we recommended a management contract. In October 1970 we prepared a brief which indicated the services which the prospective management contractor would be expected to provide. Intensive interviews with a dozen selected firms then followed, after which six firms were asked to submit their written proposals. Following further intensive interviews in the contractor's offices, George Wimpey M. E. & C. Ltd. were finally selected.

The management and co-ordination of three different design organizations; architect, Carlsberg Process Design Team and our own design teams, coupled with the integration of the Management Contractor, required a formalized management set-up which is shown diagrammatically (see Fig. 1).

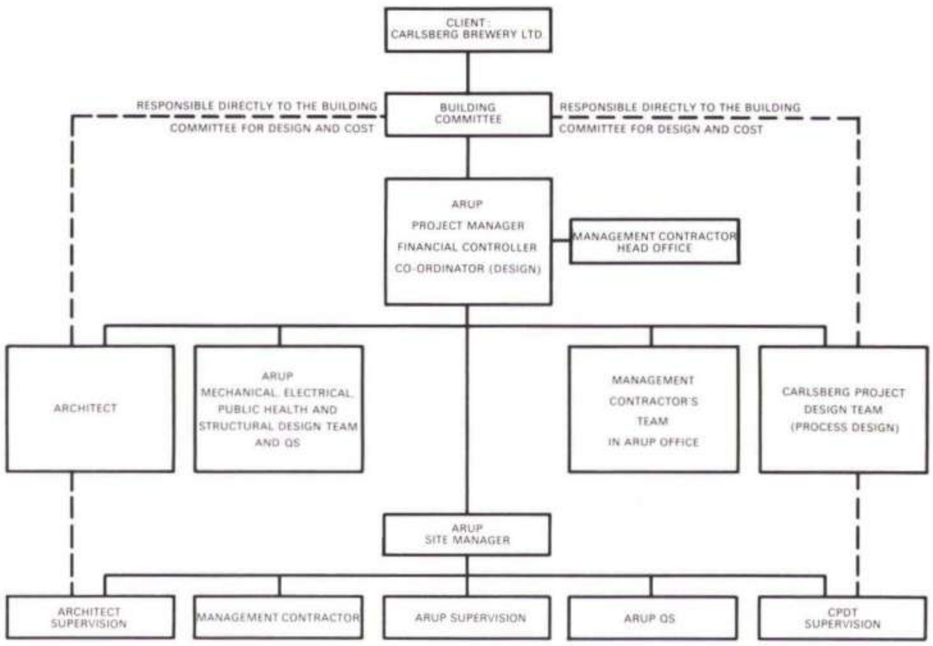


Fig. 1

Formalized management set-up
enabling co-ordination of the three design organizations

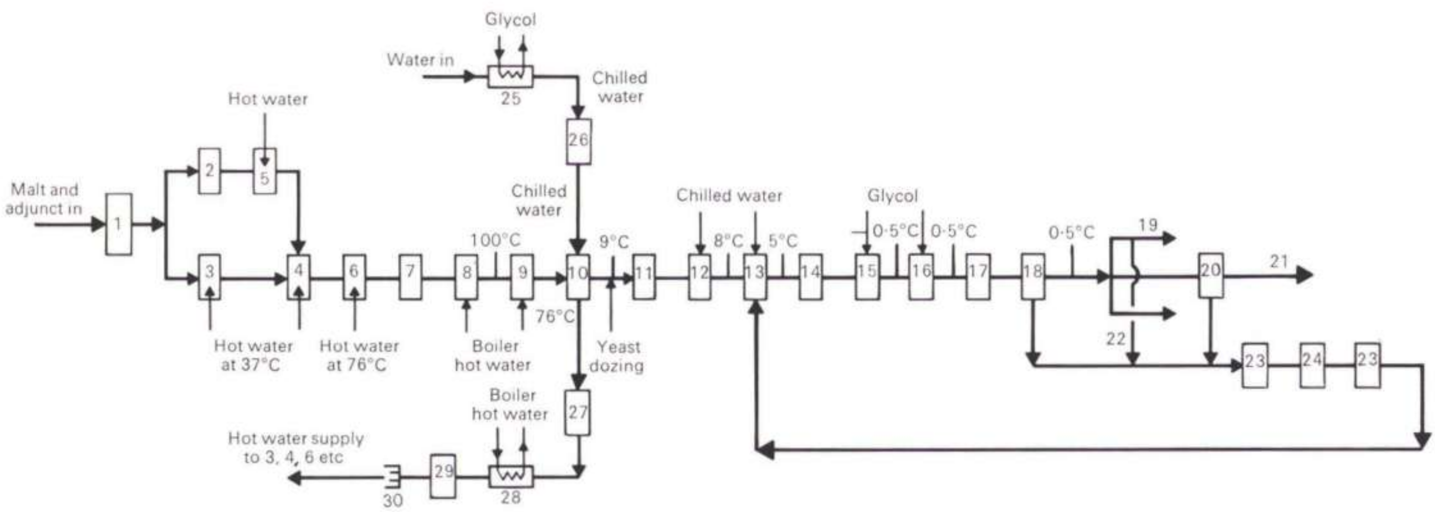


Fig. 2

Brewing: Schematic process diagram

Key

1 Malt and adjunct intake and silo
2 Adjunct hopper
3 Malt hopper
4 Mash tun
5 Mash kettle
6 Lanter tun
7 Pre-run vessel
8 Wort kettle
9 Whirl pool
10 Wort cooler
11 Gauging vessels
12 Fermenting vessels
13 Storage vessels
14 Chiller carbonator
15 Glycol/beer heat exchanger
16 Treatment tanks
17 Filters
18 Bright beer tanks
19 Bottling line
20 Keg beer pasteuriser (0°C—68°C—8°C)
21 Kegging line
22 Bulk despatch
23 Beer recovery tank
24 Recovered beer pasteuriser (0°C—68°C—8°C)
25 Glycol/chilled water heat exchanger
26 Chilled water tank (4°C)
27 Hot water tank (75°C)
28 BHW/heat exchanger
29 Hot water tank (80°C)
30 Mixer-supply hot water

Beer and Lager

What is 'beer' and what is 'lager'? What do beer and lager consist of (apart from alcohol!) and what ingredients are used when brewing them?

Although a brewery looks impressive and complicated, the basic process is really rather simple. Brewing is not difficult. One can do it oneself either by buying a kit at the chemist round the corner or by using the four ingredients which both beer and lager are made of: water, malt, yeast and hops.

The difference between beer and lager is mainly this. Lager has less sugar added to it than beer; it is bottom fermented while beer is top fermented; it has a longer fermenting period than beer; it is cooled at a lower temperature than beer and finally, it requires a longer storage time to mature. All this results in more fermenting and storage space and, therefore, a more expensive brewery.

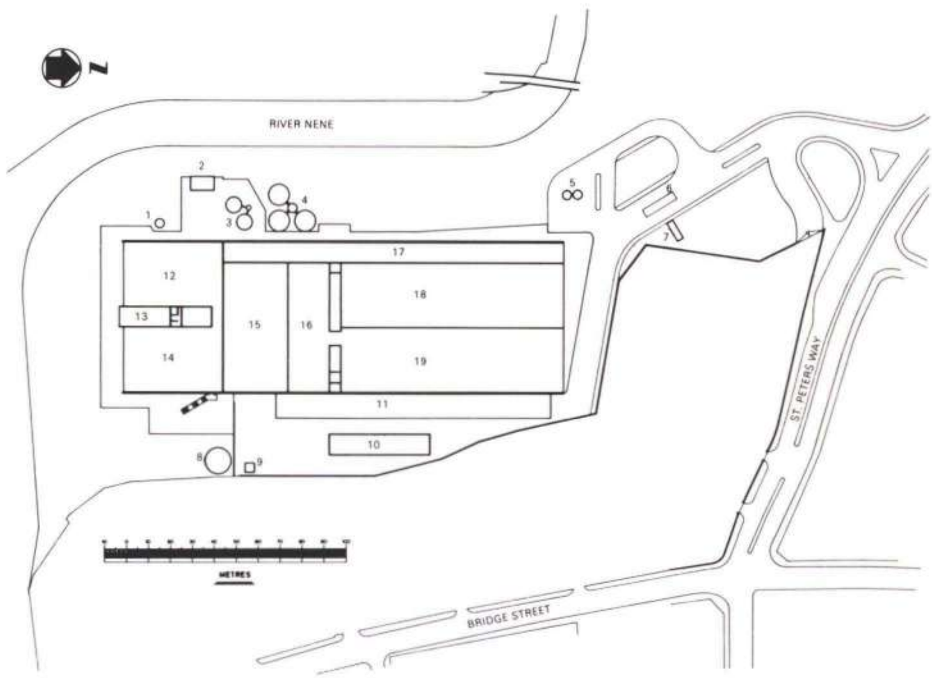
Although the basic principles are simple, a modern brewery is complex as will be seen from the schematic process diagram (Fig. 2).

Carlsberg Brewery Structure

Foundations

Initially, the River Nene was diverted to flow west and south of the proposed brewery buildings. As a result of the site investigation, showing approximately 5 m of fill overlying blue clay, it was generally found necessary to use piles, except in the deep basement area, where the 9 m depth allowed the use of spread footings. Allowance was made in the design for possible settlement of the deep basement relative to the rest of the building.

In situ driven piles were most suitable for the ground conditions and the first of 1900 piles was driven in July 1971, to a depth of 9 m. In order to avoid displacement, the casings of all piles within a radius of seven diameters of each other were driven to final depth before concreting. Two pile sizes giving 60 and 80 tonnes bearing capacities were used. The 9 m deep basement was constructed inside a permanent cofferdam of Frodingham 4N sheet piles. This cofferdam was connected to anchor piles approximately 7 m from its face by 65 mm diameter rods at 2.9 m centres.



Key

1 Chimney
2 Gas Meter House
3 Water Storage Tanks
4 Treatment Tanks
5 Spent Grain Silos
6 Weighbridge
7 Gatehouse
8 Malt Silo
9 Malt Intake
10 Bulking Canopy
11 Loading Bays
12 Energy Centre
13 Centre Core
14 Brewhouse
15 Fermenting Cellar
16 Workshops
17 Western Corridor
18 Bottling and Kegging
19 Storage

Fig. 3

Site plan

Sub-and superstructure of main building

The main structure consists of in situ, reinforced concrete, flank walls with a folded plate roof of in situ reinforced concrete over the Energy Centre and Brewhouse and precast prestressed concrete elsewhere. Lateral stability is provided by the centre core between the energy centre and the brewhouse and by the corridor block west of the fermenting cellar and bottling hall. These stabilizing blocks have in situ concrete cross walls and precast double-T floors.

Structurally, the building can be considered as five distinct sections:

(a) The energy centre and brewhouse complex
(b) The fermenting cellar
(c) The deep basement
(d) The bottling hall and storage area
(e) The corridor block.

(a) *The energy centre and brewhouse complex*

This is the most dramatic part of the brewery. It faces on to the river promenade to the south, with the brewhouse and energy centre plant exposed to view through the 26 m high glazed south façade. The massive flank walls are of in situ reinforced concrete 1 m thick, rising to a maximum height of 37 m. 400 mm diameter steel void formers at 600 mm centres were incorporated to save concrete and to reduce the weight of the walls.

The centre core which houses electrical and ventilating equipment between the energy centre and the brewhouse is of conventional construction with in situ walls and shafts and double-T floor units.

The energy centre and brewhouse roof spans 29 m from flank walls to centre core and is of folded plate construction, 200 mm thick with troughs 2.5 m deep. The rear portion drops 20 m to the fermenting cellar at an angle of 65°.

In order to provide access for construction work at ground floor level at the same time as the roof was being constructed, structural steel trusses, temporarily supported at mid-span by scaffolding towers, were used to support the formwork, reinforcement and freshly-placed concrete. The structural steel trusses formed part of the reinforcement to the folded plate construction which is designed as a semi-composite structure.

The brewhouse and energy centre plant is supported on steel-framed platforms completely independent of the concrete shell. To allow flexibility of pipework and plant installation, no cross-bracing is incorporated in the frames which rely on portal action for stability. These frames rise to a maximum height of 18 m. The glazing frames to the south façade are mounted on UB structural steel mullions, 838 mm deep at 4.8 m centres extending from floor to roof, a distance of 25.6 m. The mullions are stepped back twice to give a profile reflecting that of the roof line. The façade is stiffened by Warren trusses on the steps, which span from flank wall to centre core. These trusses are of circular hollow sections to contrast with the bold line of the mullions. Allowance is made in the joints at the walls for temperature movement of the trusses. Sealing between frames is by two-part polysulphide.

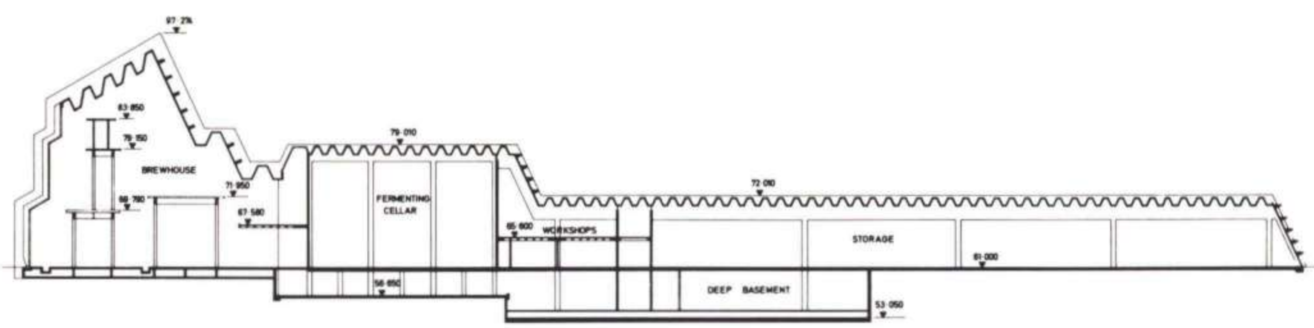


Fig. 4

Longitudinal section through the brewery

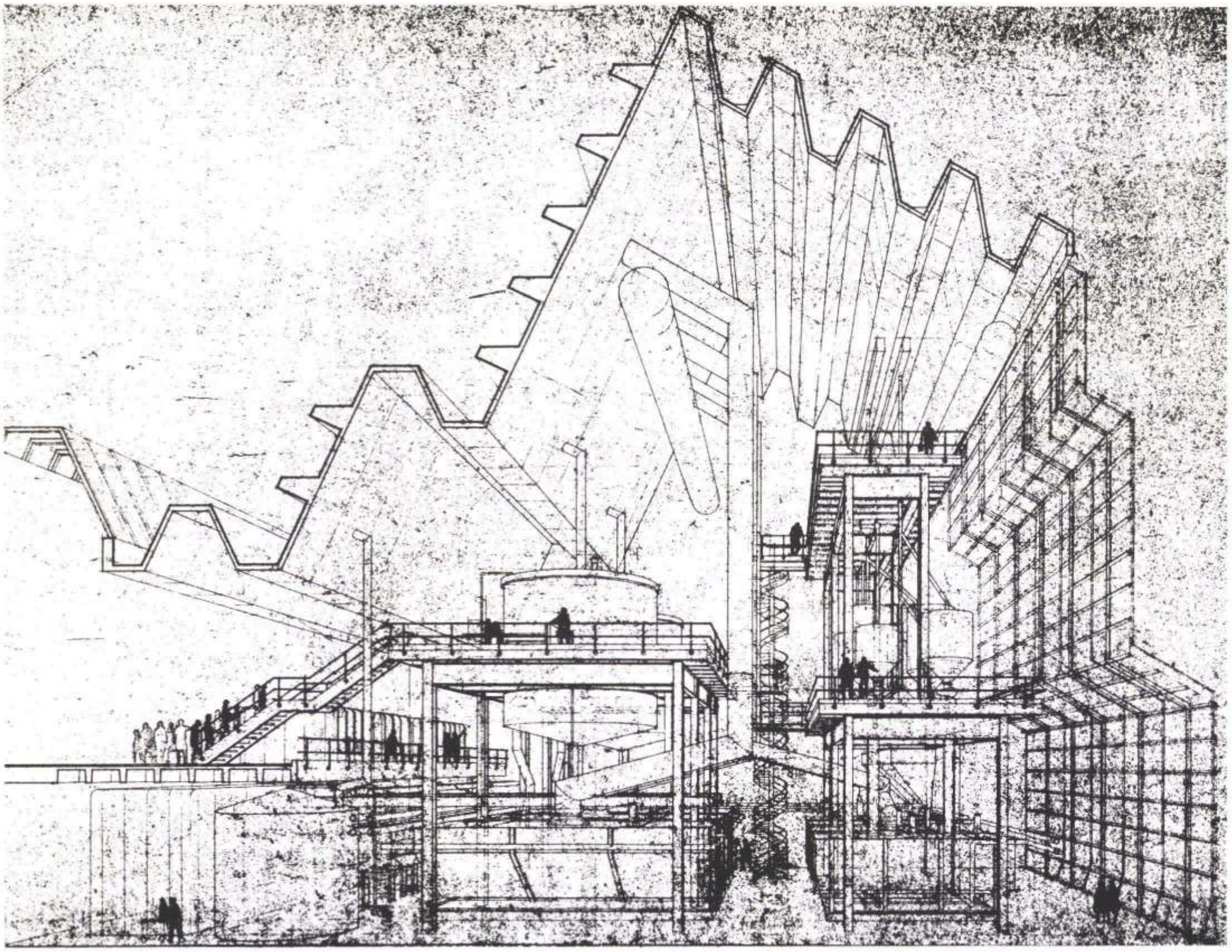
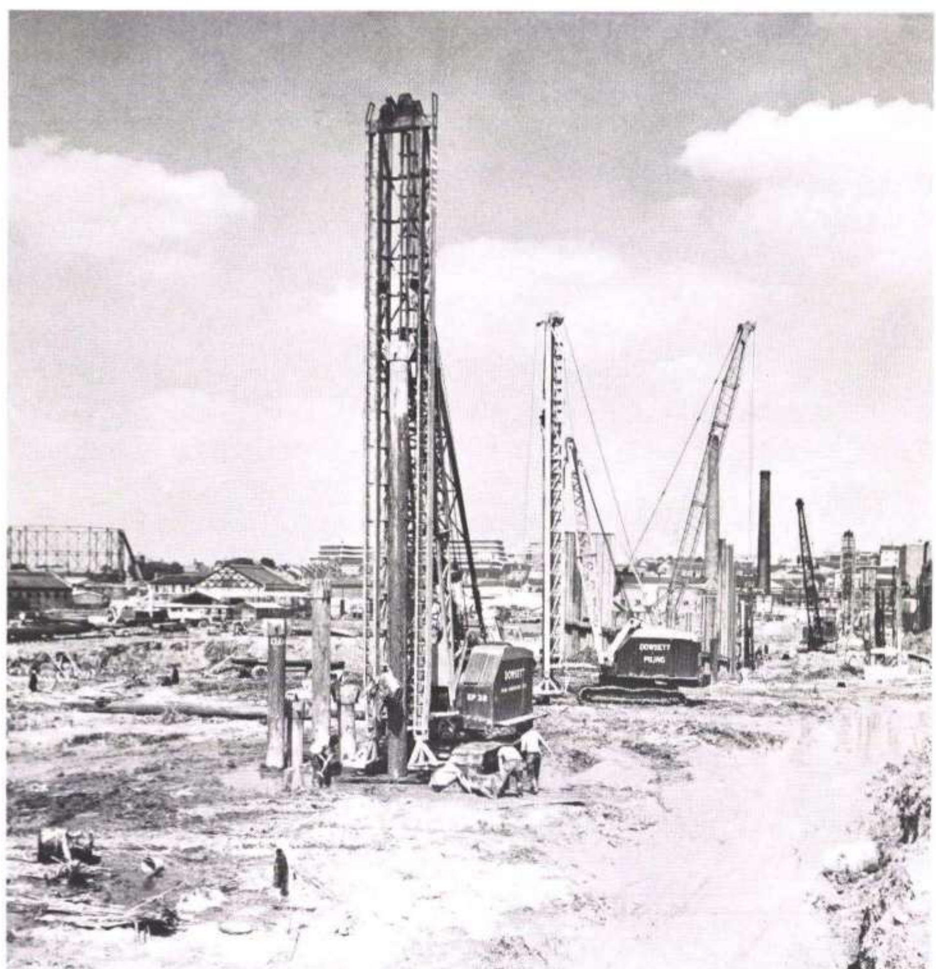


Fig. 5
Architect's drawing, showing interior, one wall removed



Right:
Installation of piles in July 1971

(b) *The fermenting cellar*

The room containing the fermenting tanks is traditionally called a 'cellar', but in this case is almost entirely above ground level. The construction here, as in the remainder of the building, with the exception of the corridor block, consists of in situ concrete flank walls with a folded plate roof. The roof units are precast inverted trough section 100 mm thick and 1.2 m deep. They span approximately 19 m between roof beams. Each unit is pretensioned with 10 13 mm diameter low-relaxation seven-wire strand.

In order to reduce the overall construction time of this section and thereby allow more time for the installation of the fermenting tanks, the columns and main roof beams were also precast.

(c) *The deep basement*

The deep basement has a plan area of 4200 m². It is 9 m deep and 5 m below normal ground water level. To avoid flotation during construction and to provide a factor of safety against flotation during normal operation of the brewery, a pressure-relief system has been incorporated in an undercroft which also accommodates the drains.

(d) *The bottling hall and storage area*

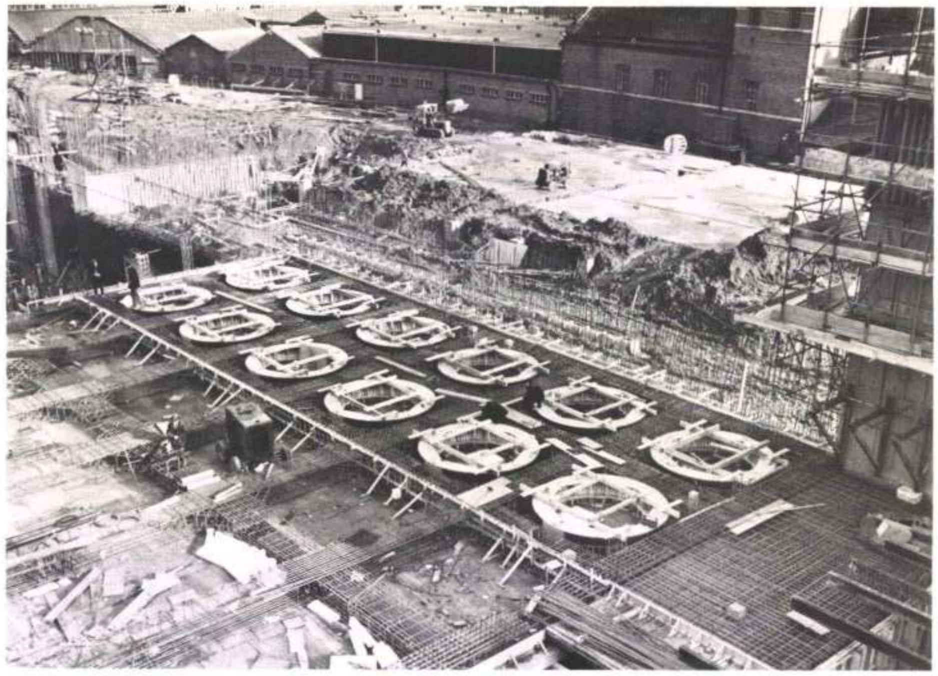
The bottling hall and storage areas constitute the main part of the low-rise section of the building and extend for approximately 125 m. The building envelope is the same as for the fermenting cellar section, with in situ reinforced concrete flank walls and precast folded plate roof units. The main spine beams and columns in this case, however, are of in situ reinforced construction. The H-shaped beams are 2.25 m deep and 1 m wide.

The roof units are mechanically bonded to the corridor wall and to the spine beams. Temperature movement is accommodated by means of rubber bearing pads on the corbel on the east flank wall. This 600 mm thick wall also supports a 12 m wide cantilever structural steel canopy over the external loading bay. This canopy is stayed back to the wall with 115 mm diameter hollow tubes which splay out in sets of four from hinged supports on the wall.

The north façade of the brewery, at the end of the bottling hall and storage area, consists of precast concrete units supported by in situ concrete A-frames. The detailing of the precast units allows for their re-use should the building be extended.

(e) *The corridor block*

The three-storey corridor block west of the fermenting cellar and bottling hall consists of in situ reinforced concrete walls with precast double-T floor units. The in situ staircases and electrical substation crosswalls provide the necessary lateral stability both for the block itself and for the adjoining fermenting cellar, bottling hall and storage area.



Above: Fermenting cellar: ground floor slab

External structures

The main external structures, apart from the 44 m high steel chimney and the beer storage tanks, are the two cylindrical concrete water tanks to the west of the energy centre and the malt silo to the east of the brewhouse. These structures are of reinforced concrete.

The water tanks are 8 m in diameter and 28 m high. The walls are 425 mm thick and were designed to resist a 19 m head of water. The tanks were lined internally by an epoxy lining.

The nine-cell, 36 m high, malt silo is 10.4 m in diameter. It has a 3 m diameter central access core which, together with the radial cell walls, is supported by the external wall.

Concrete mixes

With concrete from six different contractors on site it is evident that many different mixes were used on this project. Only one of the mixes is of sufficient interest to record here, however, and that is the one used for the flank walls. The minimum strength requirement was 30 N/mm², but the concrete was also required to meet maximum surface absorption limits.

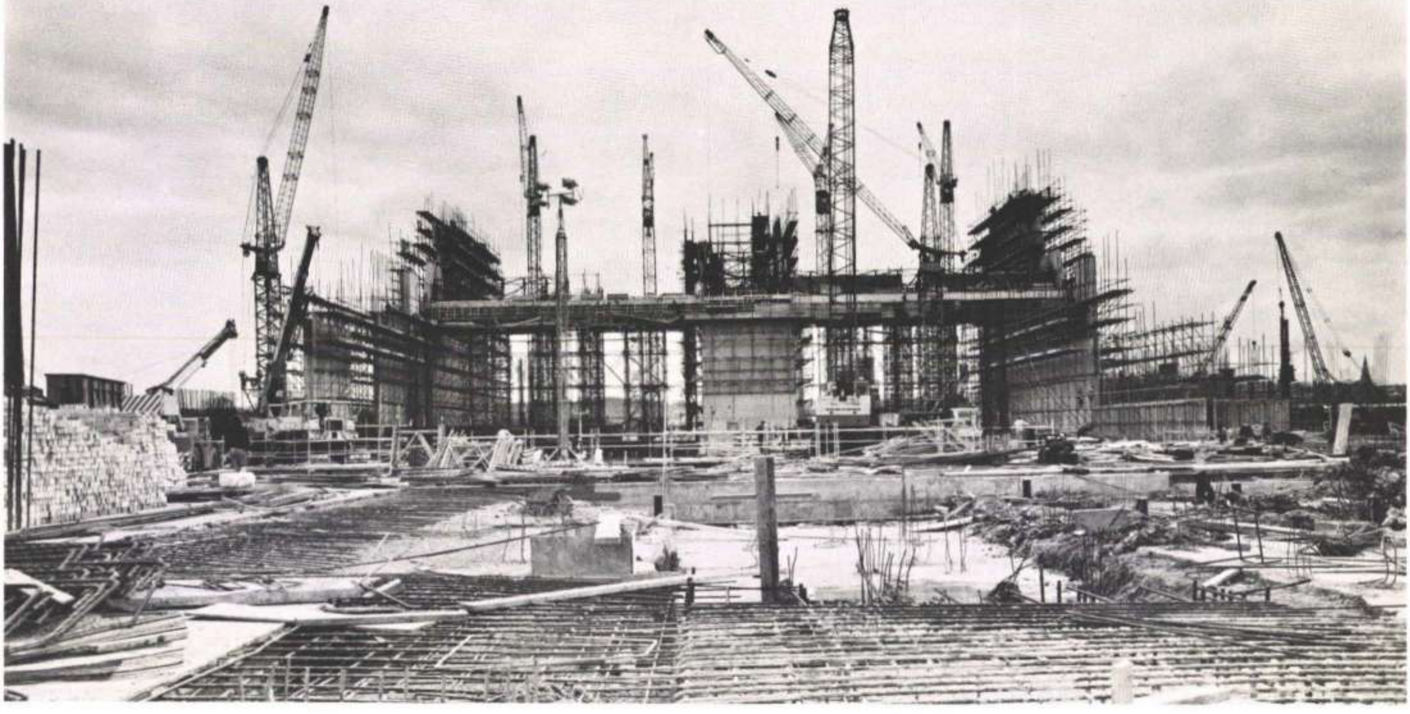
The final mix proportions were as follows:

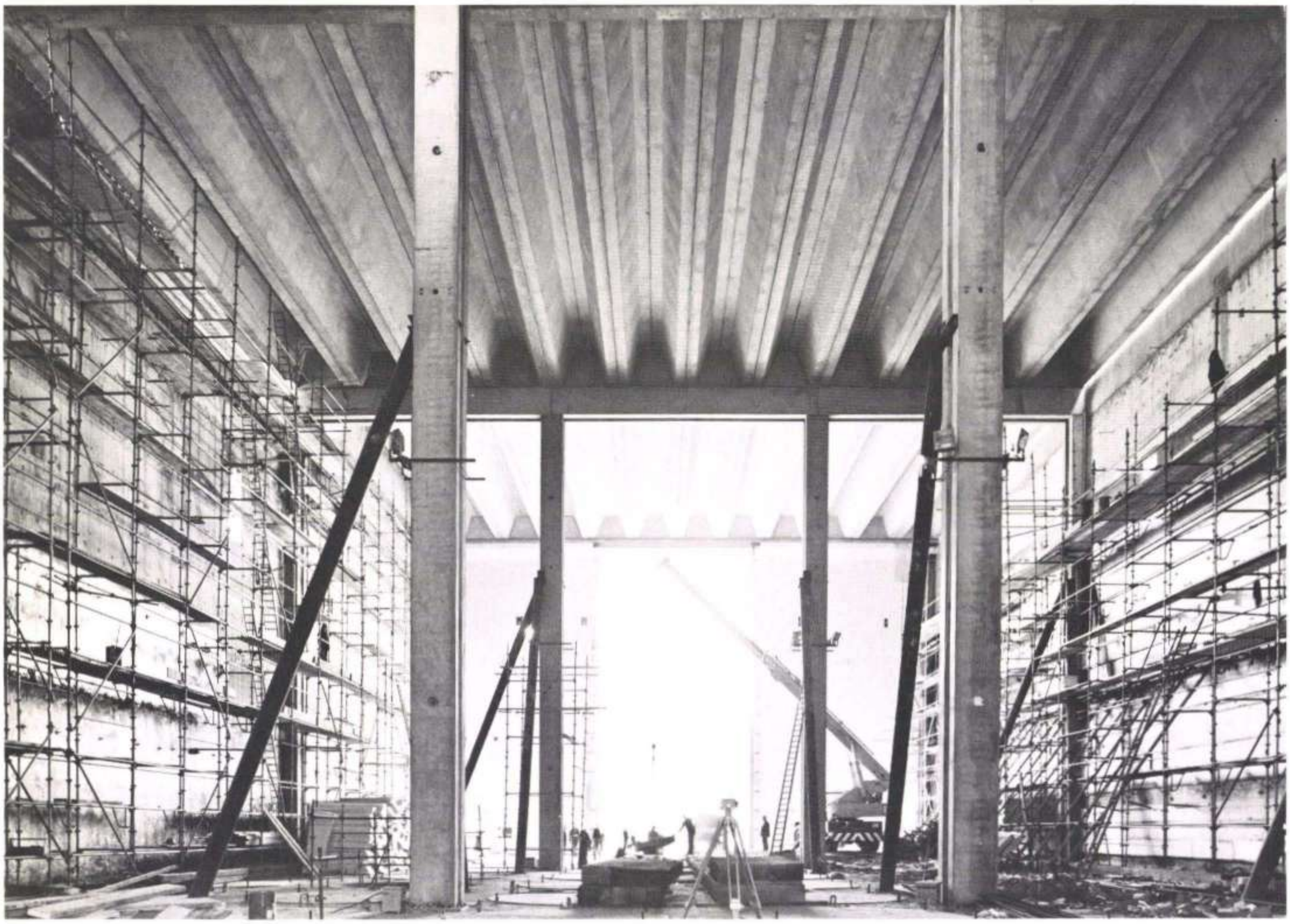
Cement	365 kg
Wellford sand	775 kg
9.5 mm single size aggregate	465 kg
19 mm gravel	700 kg
Sika BV40	600,000 mm³/m³

Formwork to flank walls

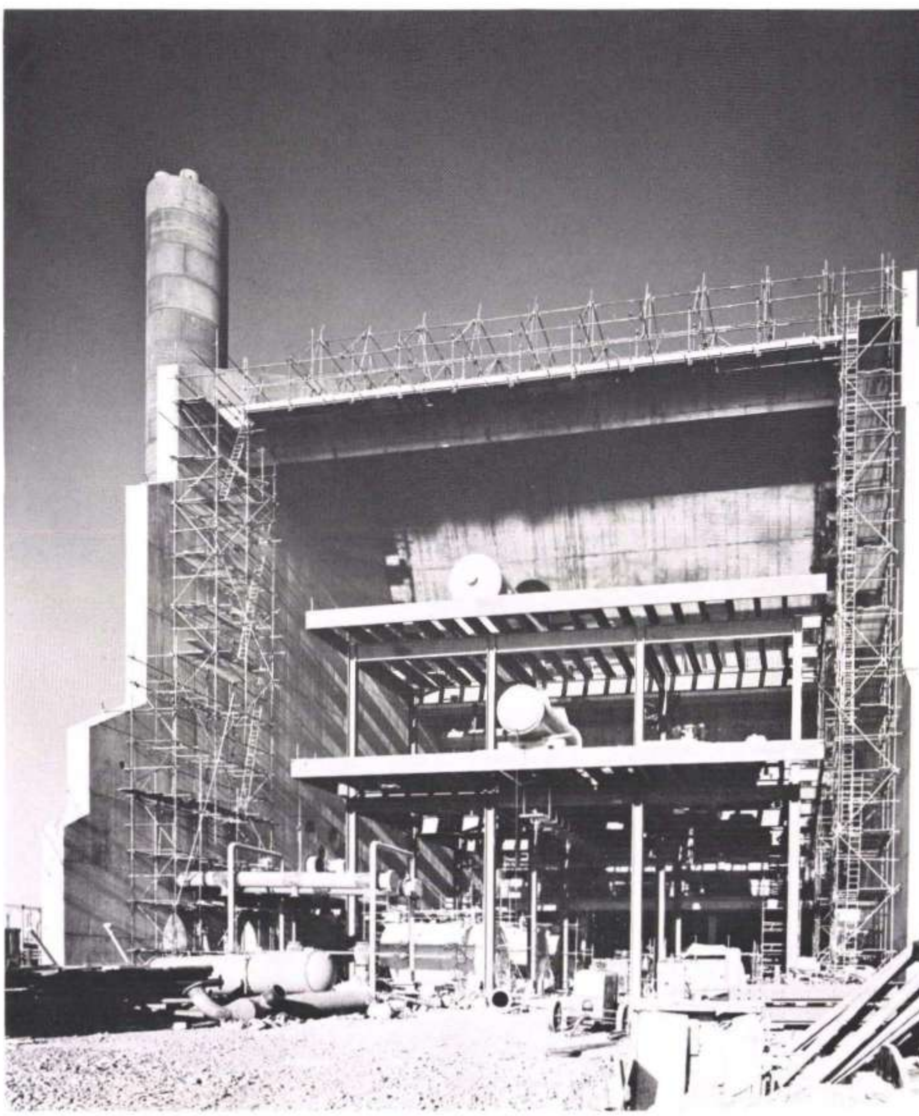
Wisaform resin-faced plywood was used in the formwork to the flank walls. Great care was taken to use boards of the same shade to obtain uniformity in the finished concrete surface. The formwork itself was built to cabinet-maker standards – as can be seen from the alignment of the rebates in the walls.

Below: Flank wall construction

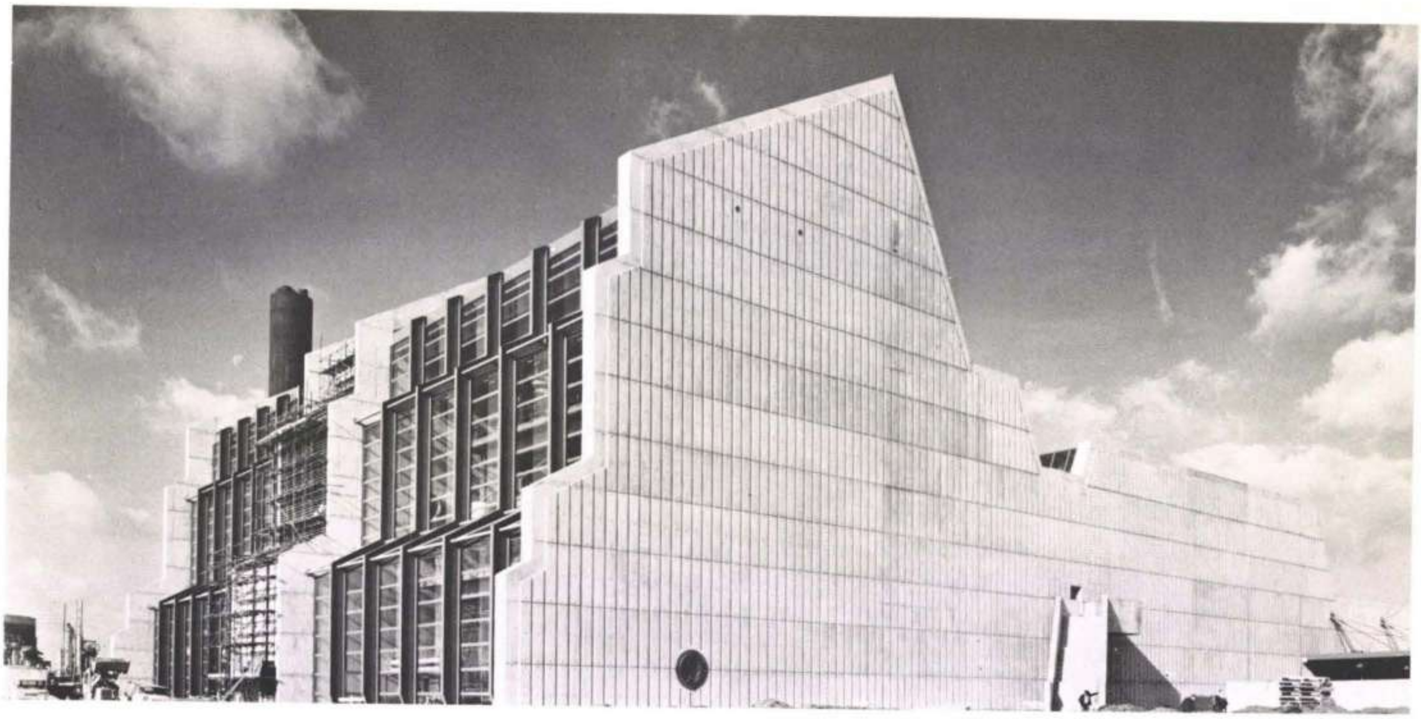




Above: Fermenting cellar under construction, October 1972 showing temporary opening for installation of tanks



Right: This view illustrates the problems overcome during the erection of plant on the platforms.
The ground floor contains the boiler plant and associated equipment, CO_2 recovery and liquification equipment, air compressors and process cold water plant.
The first floor comprises refrigeration equipment, i.e. compressors which weigh about 10 tons, an evaporator and condensers which weigh about 40 tons.
The second floor contains glycol storage tanks of approx. 20 tons and all the pumping equipment associated with it which needs to be acoustically sound and vibration free.



Above: East façade of brewery

Below: West flank wall, treatment tanks and water towers

(All photos in this section: Colin Westwood)

Roof finishes

The shape of the roof obviously presented particular weatherproofing problems which were not made easier by the fact that a 'U' value of 0.227 W/m²/°C was necessary for the roof over the fermenting cellar. This meant that relatively thick layers of external insulation were necessary which had to remain stable on the 65° slopes of the roof and be capable of resisting corner loads at the top of the roof units. In addition to this, the building, with an exposed roof area of approximately 20,000 m² had to be made watertight in 20 weeks. It was evident that conventional systems could not economically meet this programme, and Evode Ltd. were finally employed to weatherproof the roof using their own built-up waterproofing system.

In the case of the fermenting cellar roof the finish consists of an asbestos-based felt underlay as vapour barrier, 100 mm of ICI roofing board, a second layer of asbestos-based felt and four coats of brush-applied bitumen emulsion. Cork insulation is used over the energy centre and brewhouse and 38 mm of ICI roofing board over the bottling hall. Otherwise the waterproofing is as for the fermenting cellar. The final finish is red-brown in colour and gives the roof an overall AB fire rating.

Temporary waterproofing was achieved by relying on the vapour barrier only and this proved sufficient to allow the completion of internal finishes and the installation of plant. A major fire broke out on the roof of the fermenting cellar on Saturday, 2 June 1973 as the final waterproofing layer was being applied. Fortunately, no structural damage was done to the concrete structure and the overall construction programme was not affected.

Cold room insulation

A characteristic of the fermenting cellar and most of the deep basement rooms is that they are maintained at low temperatures.

This necessitated thermal insulation of the whole exterior structure of these rooms and many interior walls and ceilings. Consideration was necessary of problems associated with cold bridges, condensation and expansion and movement of the building. Many structural and architectural details were specially designed to overcome these problems in association with the insulation materials and construction.

The basic materials used were a trowelled bitumen rubber emulsion vapour barrier and extruded polystyrene slabs with a finish of either plaster and paint or plaster, nylon mesh and paint, the whole construction supported and strengthened by treated timber battens.

Carlsberg Brewery Mechanical Utilities Services

Introduction

The Client's own design team, the Carlsberg Process Design Team (CPDT), was responsible for the design of all process equipment, that is, all plant and interconnecting pipework which is directly related to beer. CPDT provided Arups with the initial mechanical and electrical services' load requirements. All process plants were, however, eventually ordered on a design/construct basis and the final services load requirements for our designs were confirmed by the relevant plant manufacturers.

In order to ease the co-ordination, it was agreed at an early stage to terminate mechanical services to manifolds surrounding process areas. The process contractors provided the connections from manifolds to the plants.

The mechanical services provided are:

1 Those serving process plants
(a) Process cold water
(b) Boiler hot water
(c) Steam
(d) Refrigeration
(e) Equipment cooling water
(f) Compressed air
(g) CO_2
(h) Distilled water
(i) Drainage.
2 Auxiliary services, environmental control and safety
(j) Drinking water
(k) Fire fighting
(l) Ventilation and air conditioning
(m) Low pressure hot water
(n) Domestic hot water.

See also Fig. 6 showing part outlines of system distribution network.

Process cold water

All water is supplied by the Mid-Northamptonshire Water Board. The supply is by two 300 mm diameter mains which merge into a 380 mm diameter main. Water for the canteen and gate house and drinking water for the brewery is taken direct from the main after the water has passed through a meter which measures the total water consumption. Two 6750 hl water tanks are fed by 300 mm diameter mains. From each tank two discharge connections are taken off, one for process cold water and one for the fire fighting installation.

A pumping set consisting of two hydro constant-speed pumps and three fixed-speed pumps maintain a constant practical working head on the process cold water system throughout the brewery.

Boiler hot water system

Hot water with a flow and return temperature of 174°C/149°C is supplied by three 9379 kw and one 2345 kw fire-tube, gas fired boilers which are equipped with forced draught fans. The only fuel used is natural gas. A maximum of two of the main boilers are required to provide the full heating load during Stage I; the third boiler is a stand-by. A fourth boiler will be necessary for Stage II. The small boiler provides hot water for factory heating and other essential heat users during periods when none of the process systems are operating, such as during a factory shut-down.

The boiler hot water system is based on flow and return headers and, in the case of the utilities services, it operates with an almost constant flow rate. The sub-headers which supply the process equipment do not always operate with constant flow rates, so they can be by-passed by control valves which maintain the flow rate in the main headers. When the flow rate through the system has been set, there is no overall automatic control to keep the rate constant. The flow will be affected by the different equipment heat demands and by the operation of the by-pass valves which maintain constant flow and return temperature. It is not intended, however, that any trimming should be done to correct these transient conditions.

The boilers each have their own complete control system and can all be operated individually, but the main boilers will normally be operated from a sequencing system in the energy centre control panel which will start, modulate the output or stop the boilers in accordance with the heat demand of the system. To maintain flow in the headers and all primary heat exchangers in the utilities system, three circulating pumps, one of which is a stand-by, serve the three main boilers. Two circulating pumps, one of which is a stand-by, serve the small boiler. Circulating pumps are started manually to give the required flow rate, and stand-by pumps are brought in manually when required.

System pressure is maintained by a pressurizing pump unit, with a nitrogen-blanketed expansion tank and atmospheric spill tank for the displaced system water.

The boiler hot water is used via heat exchangers to generate steam and low pressure hot water.

The make-up water supply for the boiler hot water system is conditioned in a mixed-bed demineralizing plant, and chemical dosing for corrosion control is added directly into the return main by means of a metering pump drawing from a chemical mixing/storage tank.

Steam

Steam for process requirements is provided by two sets of two boiler hot water/steam generators of which one of each set is for stand-by. The system supplies steam for process requirements without any returned condensate. All condensate is run to drain via thermostatic type steam traps.

Low pressure hot water

Low pressure hot water for heating in the west corridor offices is provided by two boiler hot water/low pressure hot water non-storage calorifiers. The water is pumped at varying temperatures through a natural convector system built into wall recesses under windows.

Domestic hot water

Domestic hot water for facilities in the west corridor and workshops is provided by three boiler hot water/domestic hot water storage calorifiers situated on the second floor, i.e. the

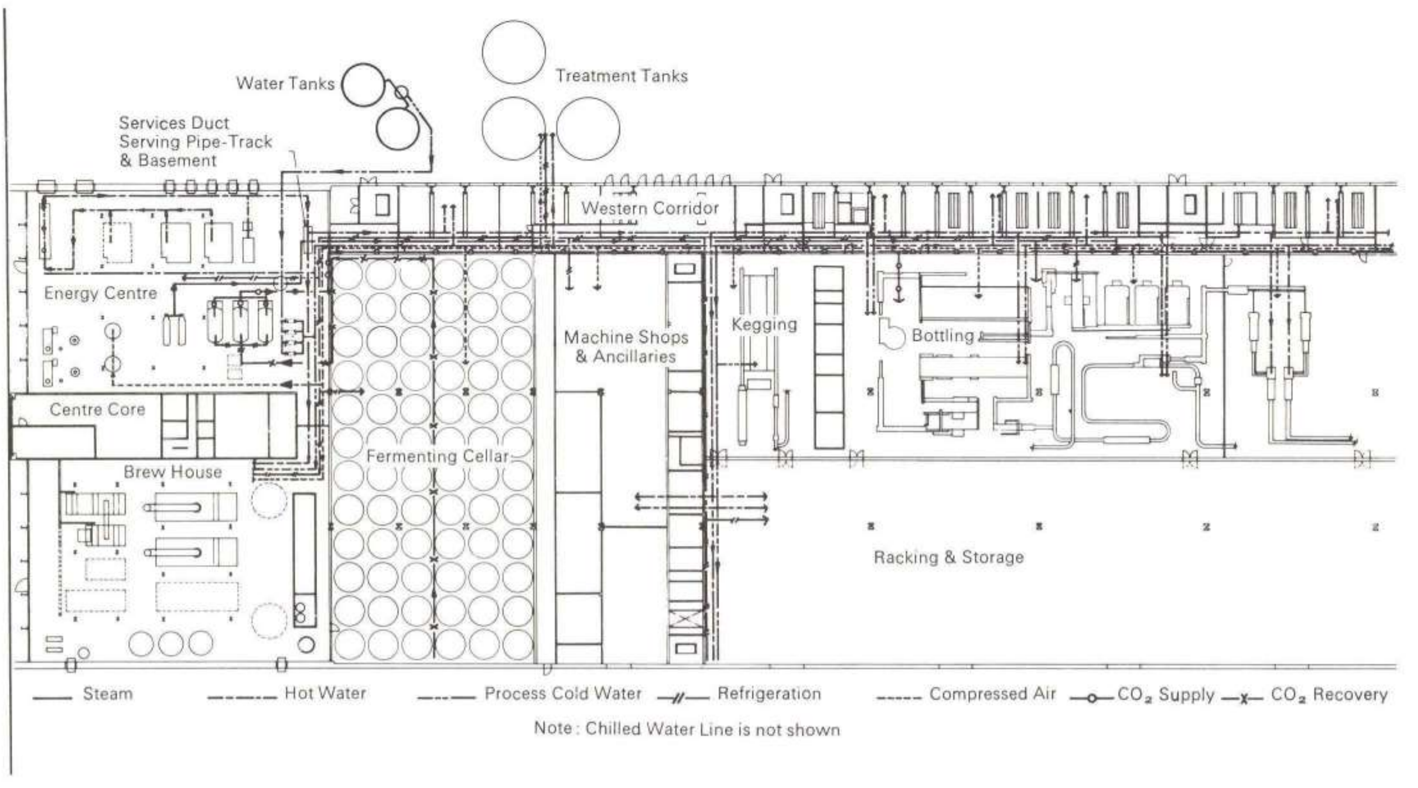


Fig. 6
Part outlines of system distribution network

pipe corridor. The calorifiers are supplied with process cold water via pressure reducing valves. The hot water circuits are kept warm by pumps which maintain a minimum circulation in the system.

Refrigeration

The refrigeration system uses ammonia as primary refrigerant and propylene glycol as secondary refrigerant. The system circulates glycol throughout the brewery to all the process cooling equipment (except fermenting and storage tanks which are cooled by chilled water) and all space cooling equipment. The glycol rises in temperature as it picks up heat and is cooled back to the designed temperature by ammonia.

Three units each designed to produce 400 tons of refrigeration have been installed, one of them as a stand-by. Space is provided for a fourth unit for Stage II.

Each unit is an independent glycol chilling unit comprising the following:

(a) Shell and tube evaporator
(b) Positive displacement screw compressor
(c) Shell and tube condenser
(d) Induced draught cooling towers with vertical spindle pumps
(e) Oil separator
(f) Oil cooler
(g) Liquid-level vessel.

In addition there is a liquid receiver which acts as a reservoir for storing liquid ammonia in case of maintenance or repair to a particular chilling unit.

The system design is based on the process requirement of glycol at a flow temperature of −6°C and return temperature of −1°C.

Glycol flow temperature	−6°C
Suction temperature	−9.4°C
Freezing temperature of glycol	−15°C
System pressure	
maximum static	262 kN/m²
maximum dynamic	297 kN/m²
maximum total	560 kN/m²
maximum working pressure	560 kN/m²
test pressure	830 kN/m²

The glycol circuit consists of:

(a) One centrifugal evaporator pump for each evaporator
(b) One centrifugal service pump for each unit
(c) Glycol storage tank
(d) Glycol feed pump.

Glycol is supplied to a number of process rooms where ceiling-mounted direct discharge blast coolers are employed for space cooling.

Glycol is also supplied to air handling units in the fermenting cellar and to the air handling plant located in the basement ventilation plant room.

Glycol is also used directly in the cooling coils of the treatment tanks.

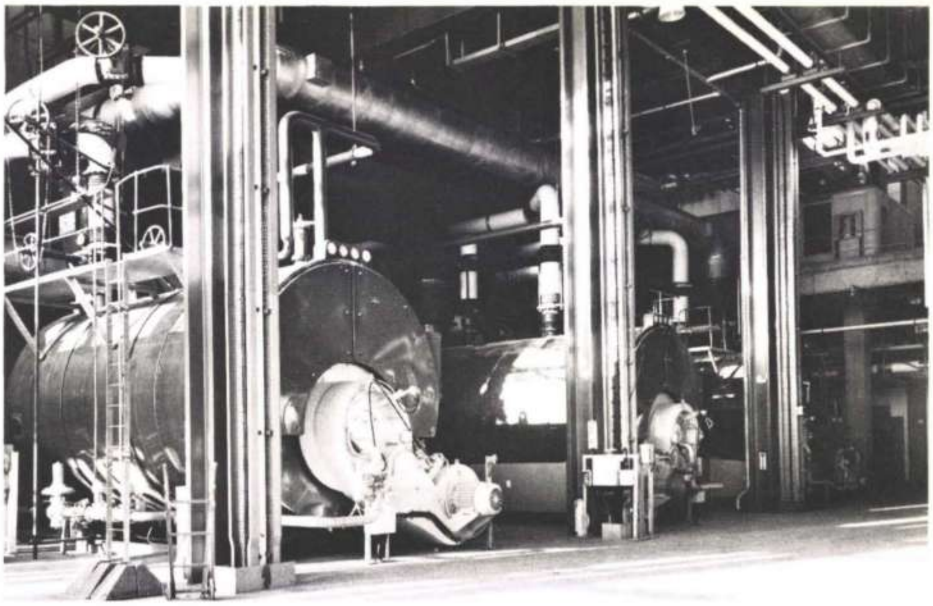
A third refrigerant, chilled water, is used to cool the fermenting tanks and storage tanks by circulating the chilled water through the jackets of the tanks. The water is cooled in three glycol/chilled water heat exchangers.

The return water from the fermenting and storage tanks is collected in chilled water tanks by gravity circulation. Each tank is provided with a make-up connection to cater for any losses and is capable of holding the total water content of the system.

The method of defrosting employed for the cooling coils in different plant and equipment is as follows:

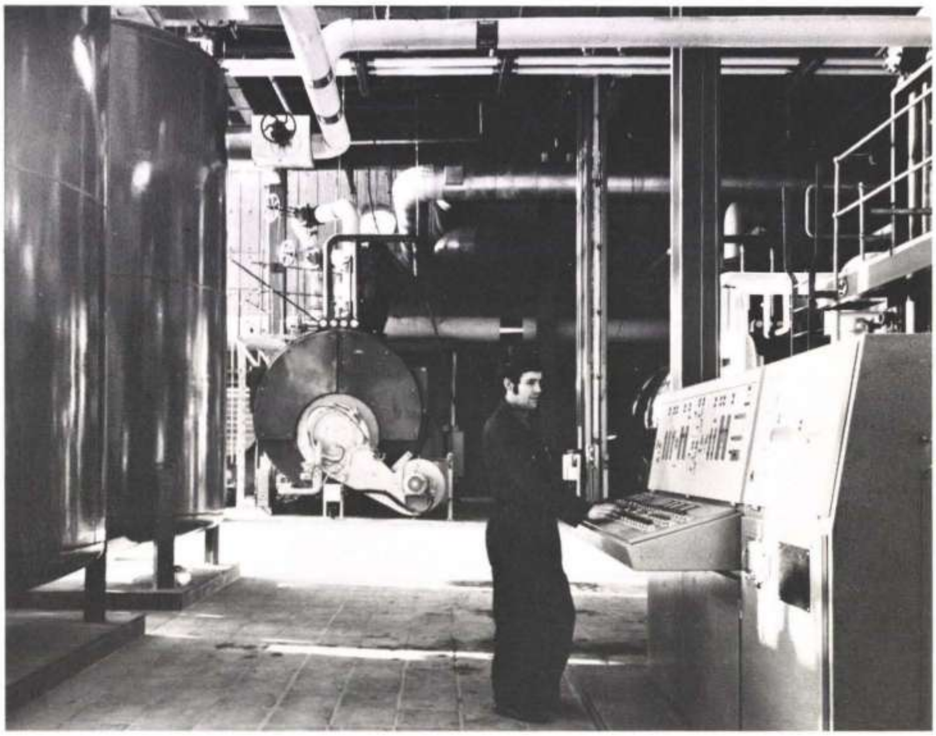
(a) Air defrost
(b) Water defrost
(c) Electric defrost.

Facilities have been provided to operate manually each glycol chilling set and during these operations a separate controller positioned on each evaporator outlet controls the capacity of the set.



Above: Ground floor energy centre showing high pressure hot water boilers
The steel columns, supporting the platforms above, incorporate the electrical cable-trays

Below: Carbon dioxide recovery plant control panel
In the background is another of the boilers



Equipment cooling water

The equipment cooling water system consists primarily of a cooling tower and a circulating pump together with the distribution pipework and necessary controls. The system supplies cooling water at a constant flow temperature to all the water-cooled equipment.

Compressed air

The compressed air system comprises two complete compressed air plants, each consisting of double acting, two stage, oil free, water-cooled compressor machines; barrel-type after-coolers; buffer air receivers/driers capable of drying air to a dew point of −40°C; filters – a ceramic pre-filter and carbon activated after-filter; main air receivers and distribution pipework. The system supplies compressed air for the process equipment and to all the control instruments.

Each machine has a capacity of 0.33 m³/sec of free air at a pressure of 826 kN/m².

CO_2

The CO_2 given off during fermentation is routed to a recovery plant. CO_2 is a by-product which is partly used in various stages of the brewing process and partly sold in the form of liquified CO_2 in returnable cylinders. Before CO_2 can be liquified it has to go through a number of cleaning processes in order to remove moisture and chemical impurities. The recovery plant has a capacity of 250 kg per hour.

Drainage

Apart from the general drainage systems a separate system has been provided to drain away the huge quantities of acids and caustics used for the cleaning-in-place process of the brewery. Sumps have been provided to receive the diluted chemicals together with necessary pumping sets to discharge liquids to the main sewage system.

Drinking water

The drinking water connection from the water main is piped to a series of drinking water fountains located in various parts of the brewery.

Distilled water

A packaged distilled water plant located in the second floor of the west corridor provides distilled water to the laboratory benches and various process areas.

Fire fighting

The present fire fighting services consist mainly of hose reels positioned throughout the brewery but water storage capacity is available to incorporate a sprinkler system in the building should the client decide to do so in the future.

Ventilation and air conditioning

The total quantity of air that is handled by different systems in the brewery amounts to approximately 1000 m^3/sec.

(a) *Energy centre and brewhouse*

The combination of the assembly of most of the heat producing plants in these two areas and the completely glazed south façade necessitates the installation of a major air handling plant in order to create reasonable working conditions during a warm, sunny summer day and to avoid any undue condensation on the glass façade.

The two areas are served by a common plant consisting of three purpose-made air handling units. Each plant comprises fresh air/re-circulation air dampers, automatic filters, a double-inlet, double-width, centrifugal fan and medium-pressure water heater batteries. All the air handling equipment is located in the centre core of this building complex. The total air handling capacity is 9339 m^3/minute.

The distribution of air is by means of circular ducts fitted with drum louvres and perforations. The diameter of the duct varies from 1–3 m.

Extraction of air is by means of axial-flow fans mounted on the east and west flank walls.

Six propeller fans mounted horizontally on the first and second floors of the energy centre platform assist the air movement between floors.

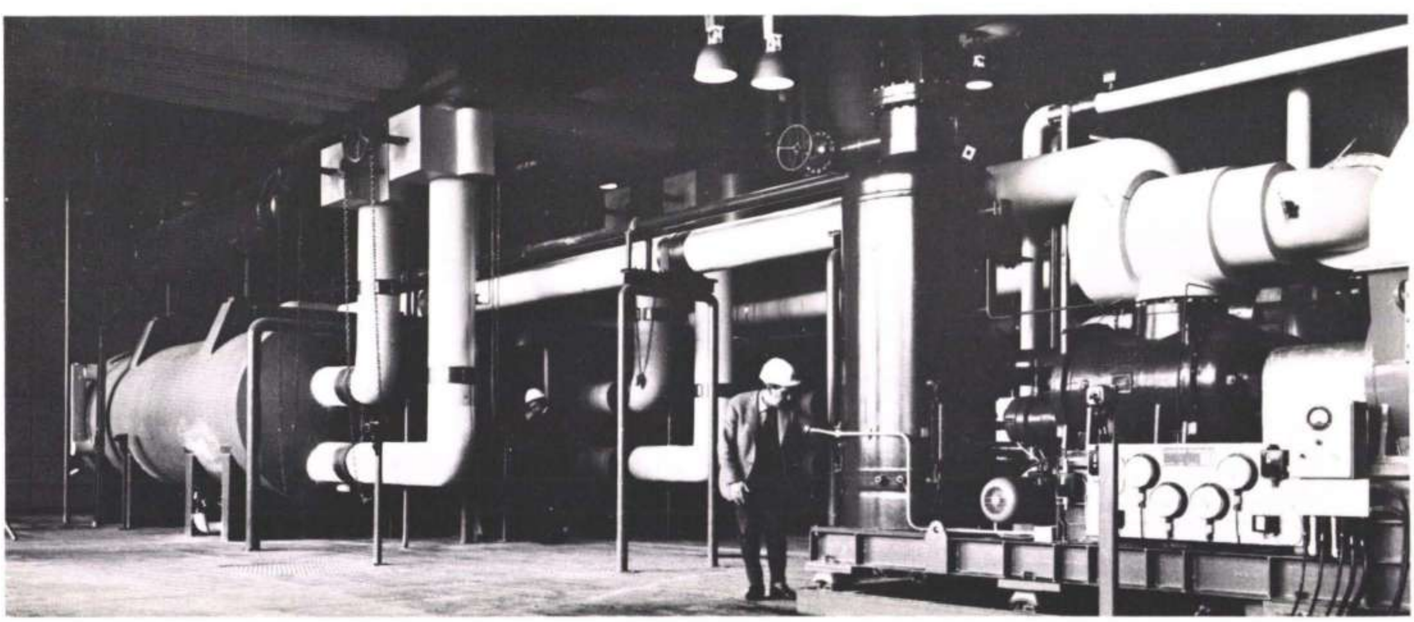
(b) *Fermenting cellar*

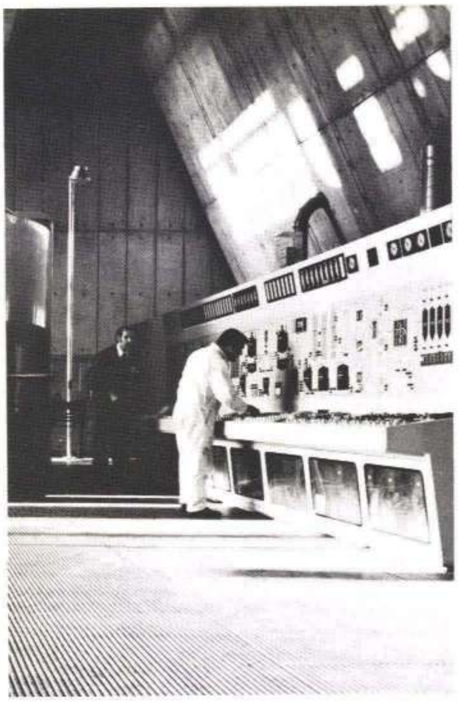
The fermenting cellar has three levels and the top level forms part of the visitors' route.

The supply air handling units discharge air via drum louvres to the top level of the cellar and via ductwork nozzles to the middle level. The bottom level has no direct air supply but air is induced into this space by pressure difference, caused by over-pressurization in the section above and negative pressure in the bottom section due to an extract system.

Left: Main intake 11kV panel

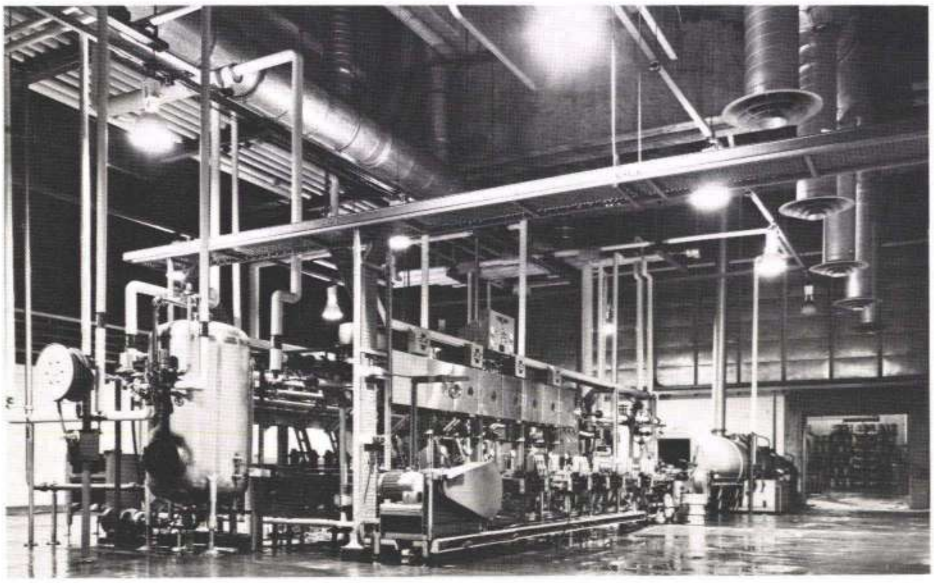
Below: The energy centre: first floor showing refrigeration equipment





Above: Brewhouse control panel

Below: Kegging plant



Below: Bottling hall: view from visitors walk way showing ventilation trunking
(All photos in this section: Colin Westwood)

An emergency extract system is brought into operation if the CO_2 concentration rises to an unacceptable level. CO_2 detectors located at the top and bottom levels stop any recirculation of environmental air and operate the supply fans and the emergency extract fans.

(c) *Basement process areas*

Most of the rooms are maintained at low temperature and have minimum fresh air supply. Cooling is achieved by glycol-fed, ceiling-mounted, blast coolers. The fresh air is supplied by a central plant and the air temperature is brought down to the room temperature before being discharged into the rooms.

A separate emergency extract system for areas where there is a likelihood of a high concentration of CO_2, e.g. the bright beer room, is provided.

In general, the temperature in the fermenting cellar and basement areas varies from 8°C to 11°C with the exception of the bright beer room where the room temperature is maintained at −0.5°C.

(d) *Bottling hall*

A large area of the brewery is taken up by facilities for the kegging, bottling and packing of beer. The bottling process leads to problems associated with moisture discharged into the environment and, to counteract this, a mechanical ventilation system consisting of four large supply air fans and two small supply air fans with an equal number of extract fans, all with associated ductwork, has been installed. Outside air is introduced into the area to maintain a safe moisture content level. In addition, several items of equipment have individual extract hoods with fans discharging directly to the outside atmosphere.

The kegging and packing areas are each equipped with supply and extract fans and ductwork. Here again the problem of excessive moisture content in the air has been considered and taken care of.

The main problem that is encountered in the bottling, kegging and packing areas is of mould growth in the building fabric, especially the roof. Mould growth not only has the devastating quality of contaminating the beer but also the tenacious habit of spreading and being difficult to remove. The ventilation systems have been designed to ensure that the moisture content in the areas mentioned above will not rise to a level which will encourage mould growth.

(e) *Laboratory areas*

These areas in general are mechanically ventilated. Within the laboratories fume cupboards are fitted with fans which discharge direct to atmosphere.

Three small temperature-controlled rooms are provided with refrigeration equipment to maintain the rooms at set temperatures – one at 20°C, one at 12°C and one at 0°C. The 12°C room is capable of being lowered in temperature to 0°C in the future.

(f) *Ductwork systems*

The ductwork sizes vary from 150 mm square to 3 m in diameter and the length of all the ductwork systems installed is approximately 3000 m. The systems carry high velocity and low velocity air.

Pipelines

The pipes used for the distribution systems vary in diameter from 13 mm to 600 mm and the total length of the pipework installed is 27,000 m.

The material specifications for the pipework are diverse and selected for the fluids that are flowing. The main specifications used are as follows:

Carbon steel	Compressed air above 50 mm diameter; natural gas; boiler hot water; steam; condensate; low pressure hot water; equipment cooling water; glycol; ammonia and condenser cooling water.
Galvanized carbon steel	Compressed air below 50 mm diameter; internal fire mains.
Cast iron	Internal, soil and rainwater drains.
Spun iron	Process cold water; drinking water supply; domestic hot water; distilled water supply (sizes up to 75 mm diameter).
Unplasticized PVC	Exhaust CO_2 gas; fermented low pressure CO_2 gas; high pressure CO_2; chilled water.
Carbon steel (galvanized after manufacture)	Liquid CO_2; CO_2 gas blow-off vent line.
Copper	Instrument air; process cold water; drinking water supply; domestic hot water supply; distilled water supply (sizes up to 54 mm in diameter.)

Total energy

There was once a definite possibility for a total energy system based on the thermal and electrical load profiles but this was rejected on the grounds of capital cost outlay.

Carlsberg Brewery Electrical Services

The electricity supply

On a crisp Sunday morning in October 1971, a team of engineers from the East Midland Electricity Board gathered on the banks of the River Nene. Their task was to install four 11 kV cables across the river from the Northampton town ring main buried in the western bank to the site upon which the brewery was being erected.

The Welland and Nene River Authority excavated a trench in the river bed to a depth of five feet and a diver was engaged to check that all was well before the cables were drawn in – the river being 8 ft. deep at the crossing point. Several bags containing a mixture of cement and sand were then dropped along the cable trench and slit open to enable a concrete seal to form above the cables.

The first step towards providing an electrical supply to the brewery was complete.

Distribution system within the brewery

The East Midland Electricity Board's supply cables are routed into the intake sub-station, situated in the centre core, where they are connected into the main 11 kV switchboard which has a fault rating of 250 MVA. The middle section of the switchboard comprising the incoming feeder breakers and bus section switches are the property of the East Midland Electricity Board and metering of the supply is effected at the bus section switches. The distribution at this point is shown in the schematic diagram (Fig. 7).

The layout of the brewery enables four main centres of electrical load to be established, these being the energy centre/brewhouse, the fermentation/treatment/bright beer areas, the workshops/kegging area and the bottling hall.

The energy centre and brewhouse loads are supplied by two 2 MVA step-down transformers, mechanically interlocked to prevent parallel operation. The 415 volts switchboard has a fault rating of 31 MVA and comprises air circuit breakers and fuse switches which feed the motor control centres and distribution fuse-boards providing the electrical supply for the machines and services within the area.

Inverse definite minimum time relays giving two-pole overcurrent and one-pole earth fault protection are fitted to the transformer feeder circuit breakers and restricted earth fault protection is included on the incoming feeder breakers to the 415 volts switchboard.

Inter-tripping facilities are provided between the transformer incomer and feeder breakers so that the transformer is isolated in the event of an overload or earth fault.

The 11 kV ring main serves three sub-stations located in the following areas:

1 The fermenting cellar
2 The bottling hall
3 The workshops

At each sub-station the voltage is stepped down to 415 volts using a ring main switchboard (two oil switches and a circuit breaker), a 1500 kVA transformer and a medium voltage distribution fuse-switchboard. Motor control centres and distribution fuse boards provide the electrical supply for the machines and services within each area.

The fault rating and protection of the high and medium voltage switchgear is as described for the energy centre and brewhouse system.

The ring is designed to operate with one switch always in the 'open' position and a system of interlocks utilizing six locks and five keys ensures this operation. A sixth key is available and enables the ring to be closed for short periods during switching operations whilst isolating a selected part of the ring. This can only be done, however, with the prior approval of the East Midland Electricity Board.

The 650 HP refrigeration compressor motors are started direct-on-line at 3,300 volts with each drive supplied by its own 1000 kVA step-down transformer.

The transformers used in the brewery are all hermetically sealed, double wound, *Pyroclor*-immersed and naturally cooled units suitable for mounting in an indoor location. A pressure release valve is fitted in the expansion chamber of each unit complete with a tripping relay for isolating the transformer under abnormal conditions.

Lighting

The lighting in the brewery falls into three main types:

1 MBF/u
2 Fluorescent
3 Incandescent.

The high ceiling areas, e.g. the energy centre, brewhouse and bottling hall, are ideal for the high bay MBF/u type fitting and these are used in all such areas with the exception of the storage area. Here it was necessary to use a fluorescent fitting since a prolonged exposure to a mercury discharge light source would have a damaging effect upon the beer.

Fluorescent fittings are widely used throughout the brewery serving the majority of the process areas and corridors. The type of fitting varies with the location, e.g. dust-tight fittings in the malt silo area and Division 2 type fittings for low temperature and high humidity areas.

Fluorescent and MBF/u fittings are generally

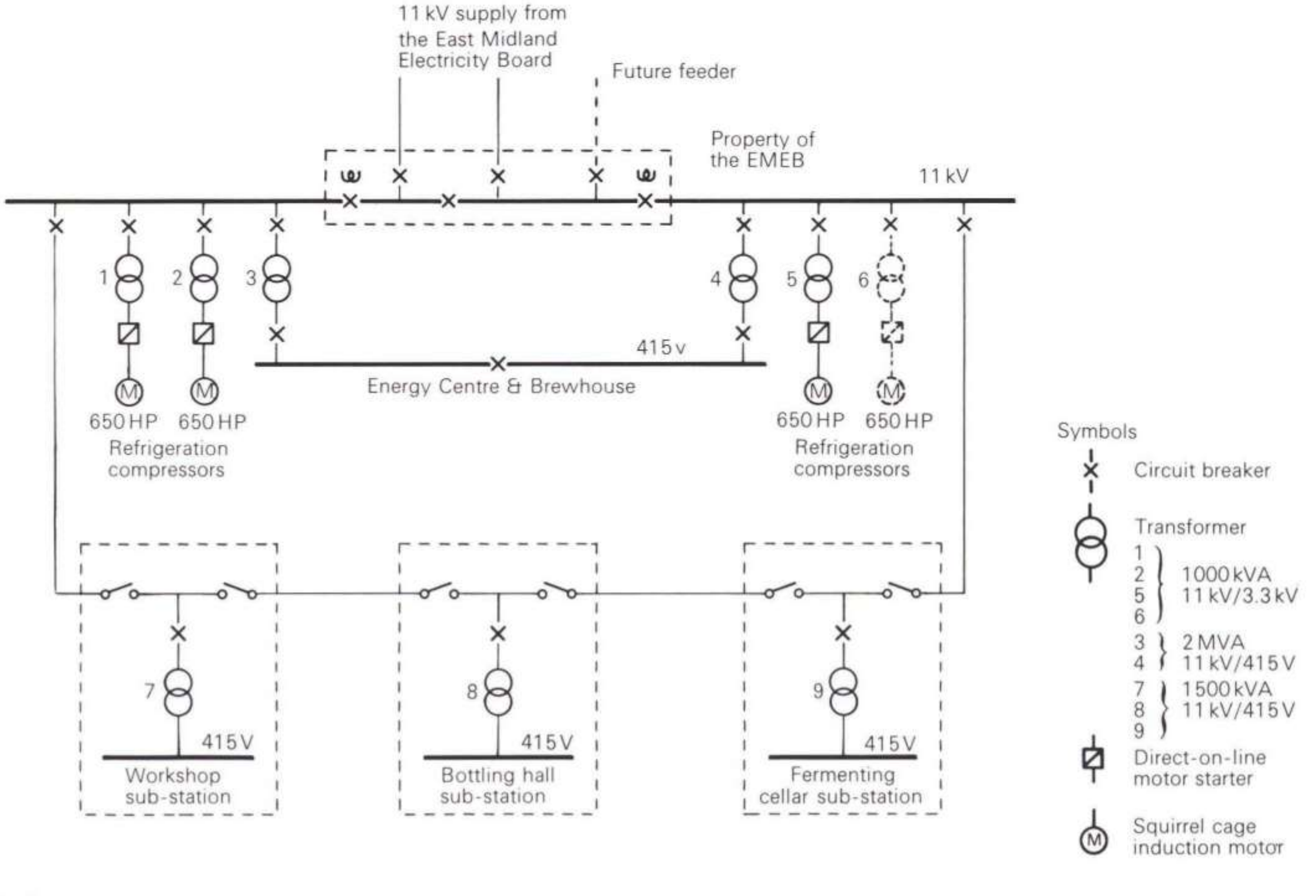


Fig. 7

Schematic diagram of electrical distribution supported from a trunking system incorporating socket outlets at pre-determined intervals. The trunking is suspended from roof inserts or from pipework supporting steelwork with supports not more than 3 m apart.

Incandescent lighting is used mainly in areas having a suspended ceiling, e.g. office accommodation, dining area, etc.

The level of illumination varies within the building from 200 lux in service areas to 500 lux in the brewhouse and energy centre.

A non-maintained system of emergency lighting is provided throughout the brewery and comprises self-contained units on trickle charge fed from a socket outlet on a normal supply or lighting fittings containing an integral emergency lamp fed from a stand-by battery bank. The application of these fittings is determined by the location, with the self-contained units serving large open areas, while fittings fed from the battery bank serve the corridors and the more confined areas.

Externally the lighting is by MBF/u lamps and varies from 125 w street-lighting fittings mounted on 5 m columns to 250 w and 400 w floodlighting fittings mounted on 7.75 m columns.

Lifts

Three lifts are included in the brewery complex, each designed to cater for both materials and passengers. The lifts are designed to cater for loads of 1000 kg, 2000 kg and 5500 kg respectively, the largest of these accommodating a fork-lift truck complete with pallett. The interior finish to the cars is stainless steel.

Telephones

Two independent telephone systems are installed comprising a GPO PABX 7 installation and a 150-extension private automatic exchange. The latter system is used solely for production purposes and instruments located with key personnel only. A 'bleep' type pocket receiver provides immediate personnel location within the building.

Fire alarm

The fire alarm installation is of the zoned closed circuit design. The brewery is divided into 24 zonal areas with each zone comprising break-glass call points, warblers, smoke detectors or heat detectors as applicable. The main alarm panel is located in the gatehouse, which is manned 24 hours a day, and a slave panel forms part of the energy centre control panel. A GPO telephone line provides an immediate connection with the Northampton Fire Brigade.

Programme

The overall programme for the project was extremely tight and in order to meet the necessary construction requirements, many items of equipment, i.e. switchgear, transformers, etc., were pre-ordered by the management contractor. The exact electrical loads were not known until the mechanical and process equipment was designed and the pre-ordering was, of necessity, based upon preliminary information which was up-dated during the manufacturing period.

Carlsberg Brewery Quantity Surveying, Contract Letting and Cost Control

As a result of the appointment of George Wimpey M. E. & C. Ltd., to act as agents on behalf of the client in the capacity of management contractor, all contracts were drawn up directly between George Wimpey M. E. & C. Ltd. and the various construction and supply contractors without directly involving the client.

Ove Arup & Partners were responsible, in conjunction with the management contractor, for the preparation of contract documents for those works we had designed, i.e. civil and structural, mechanical installations, heating, ventilation and electrical services. In addition we were also responsible for contract documentation for building work and finishes designed by the architect, Knud Munk. We were not, however, responsible for process contracts which were designed by the Carlsberg Process Design Team but were asked to give advice on contractual procedure to ensure continuity of conditions of contract, insurance, terms of payment, etc.

Basically, all civil and building contracts were awarded on the ICE Conditions of Contract, while those for mechanical, heating, ventilation, electrical and process contracts were let on the IMechE Conditions – Model Form 'A'. With a few exceptions, all contract documents were tendered for on a lump sum basis using approximate quantities.

The management contractor was responsible for measuring works in progress with construction contractors and agreeing interim valuations and final accounts. All such valuations and final accounts were, however, submitted to Ove Arup & Partners for approval before presentation to the client for monthly payments or settlement of final accounts.

The above procedure was also followed in connection with settlement of claims submitted by contractors; the management contractor being responsible in the first instance for evaluating and settling claims and only in cases of prolonged deadlock were we requested to intervene, break the deadlock and settle the dispute on behalf of the client.

Following adjustments to outline proposals submitted in April 1971, a target figure of £12.2m. was set by the client, based on an overall contract period for the completion of all works in 103 weeks. All contracts, being let on a lump basis were subject to a fixed contract period with both commencement and finishing dates firmly fixed before the signing of the contracts.

Difficulties encountered in the construction caused 'slippage' to the overall construction programme, resulting in additional costs. Accelerations to bring the work back on programme and increases due to inflation for works carried out after the dates set by the contract for completion have added further to the final cost.

Cost control on all contracts was effected in the normal way by evaluating additional works and omissions and forecasting anticipated claims.

The target figure of £12.2 m. was divided into the following five major sections of capital expenditure envisaged at the commencement of the project:

1 Section 100 – Site Works, comprising the management contractor's fee and associated site costs, equipment erection and statutory testing

2 Section 200 – Civil and Building Works, comprising 25 major contracts and 64 minor contracts, sub-contractors and suppliers

3 Section 300 – Utilities (Mechanical Engineering Installation and Heating and Ventilation Services), comprising 14 major contracts and 67 minor contracts, sub-contractors and suppliers

4 Section 400 – Electrical Installation, comprising six major contracts and 21 minor contracts, sub-contractors and suppliers

5 Section 500 – Process Installation, comprising 17 major contracts and 62 minor contracts, sub-contractors and suppliers.

Space obviously does not permit us to give the names of all the contractors listed above but the major construction contractors who carried out work under the above headings for which we were responsible could be summarized as follows:

Section 100

Management contractor: George Wimpey M.E. & C. Ltd.

Equipment erection: G. W. Sparrow & Sons Ltd.

Section 200

Cast in situ concrete piling: Dowsett Piling and Foundations Ltd.

Substructure, drainage and roadworks and part superstructure works: Kier Ltd.

Remaining superstructure works: Bierrum & Partners Ltd.

Structural steelwork: Wright Anderson & Co. Ltd.

Building elements: Henry Boot (Construction) Ltd.

Section 300

Utilities, piping and heating and ventilation services: Haden Young Ltd.

Refrigeration plant: H.T.I. Engineering Ltd.

Chimney and boiler flues: F. E. Beaumont Ltd.

Insulation: Joseph Nadin Ltd.

Section 400

Electrical installation: Balfour Kilpatrick (Installations) Ltd.

Lift installation: Evans Lifts Ltd.

Carlsberg Brewery Management Contract

George Wimpey M.E. & C. Ltd. were finally selected and in December 1970 we recommended to our client that they were employed for a trial period during the preparation of the outline proposal scheme. Their appointment was confirmed in April 1971. During the preparation of the outline proposal report, George Wimpey M.E. & C. Ltd. worked closely with us in our offices and afterwards for a short period on design, management, cost and programming.

The management structure adopted for the project is shown diagrammatically (Fig. 1).

A management contract was drawn up between Carlsberg Brewery Ltd. and George Wimpey M.E. & C. Ltd. in such a way, that it satisfied the condition surrounding the administration of contracts which were on a very tight timescale and of great complexity both technically and by virtue of the need to employ a large number of construction contractors, suppliers and sub-contractors.

George Wimpey M.E. & C. Ltd., had a substantial number of staff on the site in order to fulfill the following tasks:

Quantity surveying

Preparation of conditions of contract, measurement of works, agreement of new rates, initial settlement of claims and settlement of final accounts.

Site supervision

Detailed supervision of workmanship, checking of temporary works, site variations, safety and labour relations.

Procurement

Pre-ordering of plant and material, preparing purchase orders, monitoring works inspections and issue of purchase order revisions for variations.

Programming

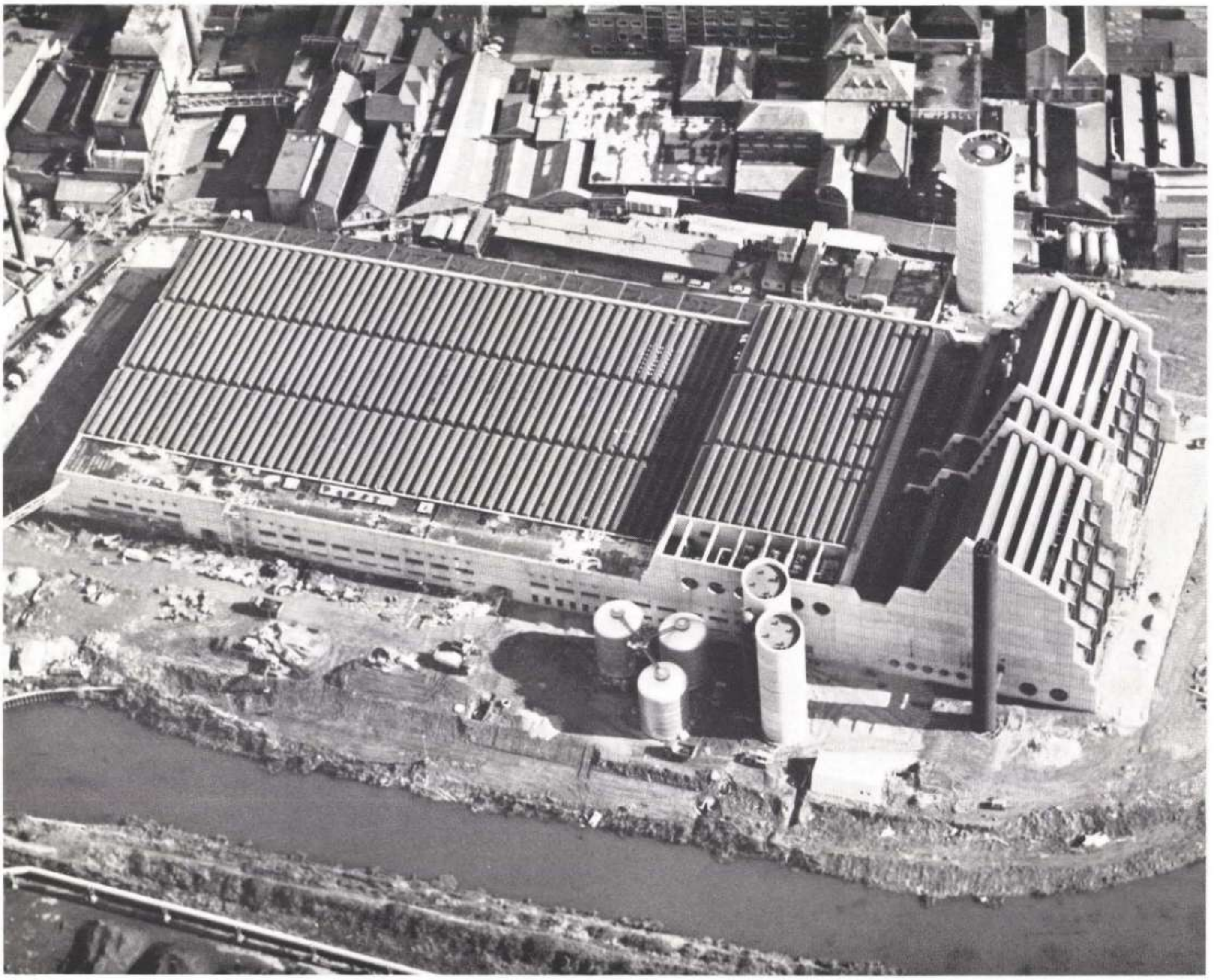
Preparing programmes for key events, preparing detailed area programmes and checking contractors' progress and monitoring programmes.

Site services

Canteen facilities for all contractors, first aid, site security and toilet facilities.

In addition, the management contractor's head office provided back-up expertise for their site staff and the overall management of their site organization which was led by a site superintendent.

Aerial view of brewery in November 1973 (Photo: John Beedle)



Lighting heating and, ventilation in multi-storey and under-ground car parks

Derek Ball
John Campbell

This paper was given at The Institution of Structural Engineers and The Institution of Highway Engineers' Joint Conference on Multi-storey and Underground Car Parks, 16–17 May 1973.

Lighting

Car parks warrant more attention and expertize in the design of lighting than they are presently generally attracting, if the best use is to be made of materials and finance.

The principal objectives in car-park lighting are worth consciously reviewing at the onset of design, and these should include the employment of lighting, not only to assist the safe movement of cars, but to mark access routes for driver guidance, to light parking bays to ease manoeuvring and minimize vandalsim and, by no means least, to present a reasonably attractive appearance commensurate with the environment of associated or adjacent buildings.

A review of contemporary car parks, particularly those below ground, reveals generally poor illuminance providing minimal guidance, shabby appearance and, in some cases, badly maintained installations which can leave one feeling only apprehensive for the safety and security of the car and its contents. Experience would suggest that vandalism in inclosed areas is a function of the environment, and in this regard, improved lighting in particular can do much to help in alleviating the problem.

Early association with design

It is perhaps a truism that lighting in car parks is too often added at a late stage in design and the finished installation reflects this error. While it should be appreciated that the nature of car park structures normally inhibits the lighting designer in what he can achieve, nevertheless an early association with the architect and structural engineer may well produce, with a reasonable budget, a better considered, more visually attractive, more easily maintained and more practical lighting solution.

A guide to the illuminance which should be provided is given in *CP 1004:Part 9:1969*[1], but it is important to remember that the quantitive criteria are recommended minima only. The installation should, where possible, within physical and financial constraints, not only comply with current standards but anticipate future trends of progressive improvement as standards are raised, by providing good lighting at the onset or by building in the necessary flexibility to permit future improvement.

As has been indicated, the restricted head clearance in multi-storey car parks presents a unique problem in that a reasonably even illuminance over the whole area, provided normally in commercial and industrial buildings, can be achieved only at prohibitive cost. This is a function of the limited mounting height and type of luminaire employed, which will require to be located on or in the structural slab at a space/height ratio not greater than 1:1.5.

Acceptable values of illuminance

Having established the basic criteria and concluded that we must abandon our normal practice of providing even illuminance over the whole floor area, it is pertinent to indicate what illuminance values, and what contrast ratios might be acceptable. Illuminance values that might sensibly be specified as a minimum in this country are between 10 and 50 lux in parking bays, 100 and 150 lux along access routes and 200 and 300 lux at entrances and exits.

Where entry into the relatively dark interior of the car park is not speed restricted by barrier or ramp, the lighting installation should be substantially reinforced in this area to provide an illuminance typically of about 1000 lux, depending on the light contrast ratio between outside and inside. Alternatively the contrast between outside and inside illuminance may be reduced by external shading in order to allow sufficient time for the eyes to become dark adapted.

Having accepted that significant contrast ratios will obtain between well-lighted access routes and the less well-lighted parking bays, it is important in the interests of recognition, to maintain a good colour contrast between the columns, floor and ceiling, to avoid veiling glare arising either directly from luminaires or reflected from hard glossy surfaces, and to provide, as far as is practicable, light coloured surfaces, in order to improve reflection and hence background luminance. For instance, light-grey concrete has a reflectance of about 55 per cent and mottled grey tiles 75 per cent.

Access route lighting

Access routes should be well illuminated, free from glare and should provide clear visual-route guidance to the driver by the placing of luminaires and by the contrast in illuminance with adjoining parking bays. The possible arrangements are necessarily limited, but two commonly employed alternatives are luminaires located directly over the centre-line of the access route, with subsidiary luminaires over the parking bays or luminaires located either side of, and parallel with, the access route, with spill lighting serving the parking bays.

The former method has the merit of strong route indication, and where the 'centre-line' luminaires are surface-mounted, the parking bay luminaires could to advantage be recessed or otherwise optically controlled so that there is no visual confusion with the route markers. The latter alternative has the merit of greater economy, but it is important to ensure that separation between the parallel lines is not too great, so that a dark ceiling is apparent, resulting in loss of guidance. An analysis of some current installations indicates the lighting load will be generally between 47–65 W per car space and 2.5–3.3 W/m² of floor area.

Selection of electrical equipment

Each local authority may apply its own particular regulations or bye-laws, but for general guidance, the *GLC London Fire Brigade (Petroleum Branch) Code of Practice*[2] for underground garages or car parks requires electrical equipment (including electric lamps), if installed below the general garage floor level or within the air stream of an extract ventilating system, or in other hazardous positions, to be of certified flameproof pattern (Group II gases). Where such equipment is installed at garage floor level or within 1.2 m above floor level, it should be of a type suitable for use in Division 2 areas (see *BS 4137:1967*[3]). All electrical equipment, is in any event, required to be suitably protected against mechanical damage and should be totally enclosed.

The foregoing basic requirements naturally influence the selection of equipment, but for general use at ceiling level in car parks, the choice is usually made from a range of commercial fluorescent batten-type luminaires, preferably suitable for use in Division 2 areas, or enclosed bulkhead type luminaires suitably certified and fitted with high-pressure mercury lamps. The tubular fluorescent lamp will normally be the first choice on the grounds of long life, good lumen maintenance, high luminous efficacy, reasonable cost and, by virtue of its linear form, directional quality. When exceptional life is required in situations where, for example, maintenance is a problem, consideration should be given to the sintered electrode fluorescent tube (SEFT). The initial cost is about 30 per cent higher over the 1.5 m single MCF/U tube enclosed type luminaire, but tube life is at least three times, i.e. in the order of 20,000 hours, and the cost difference may be recovered easily at the first tube change of the cheaper alternative. The SEFT tube has most of the attractive characteristics of cold-cathode tubing, can be tailor-made to any shape and in particular, is available in two, four or six leg types to suit a 600 mm square luminaire, with lumen outputs equivalent to 80, 125 and 250 W high-pressure mercury (MBF) lamps, ideal for recessing in a coffered slab to provide a clean ceiling with maximum clear headroom and little or no glare.

The bulkhead-type luminaire will normally incorporate a high-pressure mercury (MBF) lamp which, since it is more nearly a point source, must be more carefully employed if glare is to be avoided, than the relatively large-area, low-brightness, fluorescent tube. It can be used to advantage in lighting parking bays, and in this event, particular care must be taken to control the light output, preferably optically or by screening, to achieve a low glare factor and to avoid confusion with the linear sources lighting and marking the access routes.

Luminaires should be sealed and robustly constructed with anti-corrosion finishes since they are often called on to operate in cold and damp conditions. Where construction permits, it will normally be advantageous to employ recessed construction, which offers both visual and practical advantages in increased clear headroom and better protection against vandalism. Glazing should be dust-tight and vandal-resistant either by using a thick prismatic glass lens or a thick polycarbonate prismatic diffuser, such as Makrolon, secured with secret screw fixings. Many unsuitable and cheaper batten-type luminaires have been observed in use, with rusty, buckled and broken enclosures, filled with dust and insects, in the more aggressive environment found typically in car parks, which must surely be ample deomonstration of a short-sighted policy of too restricted a budget. Mention should be made of the tungsten-halogen lamp in the miniature 'shovel' flood-type luminaire, which has a useful application in open rooftop parking areas. The lamp is extremely small in size, is available in a wide range of outputs, but has a relatively short objective life of normally 2000 hours and only modest luminous efficacy of about 18 lm/W, compared with fluorescent tubes with an objective life of 7,500 hours and luminous efficacy of up to 70 lm/W and high-pressure mercury lamps at about 50 lm/W.

Circuit arrangement

Particularly where daylight penetration is significant, a marked saving in running costs may be achieved by divided lighting circuits, so that the inner parking area, or part of the inner area, is maintained continuously in lighting, while the peripheral lighting is switched out during daylight hours and switched in automatically by photoelectric switches at night.

Lighting in underground car parks should generally be switched remotely and selectively, floor by floor, to provide maximum economy in the use of electrical energy as floors come into use or are vacated. In addition, security lighting circuits should be switched separately from a central position and also be capable of local switching at each floor level.

Such security lighting as is installed should be supported by a battery or battery-inverter installation depending on size, arranged to monitor mains supply at each floor level and switch in automatically on local circuit failure or general supply failure. Security lighting should protect pedestrian escape routes, staircases, lift lobbies and any hazards to free movement.

Fig. 1

Car park for L. H. Beal Ltd., Osborne St., Hull. Designed by Arup Associates Architects+ Engineers+Quantity Surveyors.
(Photo: Cecil Studios Ltd.)

Where car parks are situated above ground every effort should be made to use natural ventilation. The natural ventilation rate is very dependent on the wind speed and direction, but the provision of permanent ventilation openings to the external air in the two opposing longer sides can provide sufficient cross-flow ventilation under favourable conditions. In this case the openings in each of the two sides should have at each level an aggregate area of at least $2\frac{1}{2}$ per cent of the area of the parking space at that level (making a total of at least 5 per cent per floor) and being so distributed as to provide effective cross ventilation. This illustration shows a method of achieving this.

Heating

Heating is not normally installed in underground car parks in the United Kingdom as cars are suitable for use in all but the most severe external conditions and the internal conditions are unlikely to be worse than the external ones. Heating will therefore be carried out only when it is a specific client requirement. Unit heaters are a common approach to this problem when it occurs, but it should be borne in mind that the motors and associated starting gear should be of a type safe in the presence of flammable vapour.

The only areas that need heating to provide comfort conditions are spaces like toilets, offices and pay booths. When the car park forms part of a larger development and a heating system is provided for the remainder of the building, the car-park toilets and offices can normally be supplied with heat from it. When this is not practicable electric convectors or tubular heaters provide a satisfactory solution. Pay booths can be dealt with in a similar way if they are constructed in an unenclosed space, but if they are situated in an area where exhaust fumes are likely to become concentrated they should be supplied with tempered fresh air.

Exposed ramps

The only extensive heating problem encountered with multi-storey and underground car parks is that of exposed ramps. In winter conditions with persistent low temperatures the road surfaces will ultimately fall below freezing point, and any precipitation in the form of condensation or rainfall will be converted to frost or ice. Likewise any snow that falls will become compacted and frozen. The principle of external surface heating is therefore aimed at providing sufficient heat to arrest the fall of surface temperature at just above freezing point. Heating can be carried out using a low-voltage supply to mats of steel mesh protected against corrosion, or by using a mains-voltage supply to single-core heating elements.

Car park ramps are normally constructed in monolithic concrete or have a screeded surface. In both cases the heating cable is installed about 50 mm below the finished road surface.[4] Usual electrical loads created by ramp heating vary from about 100 W/m^2 for a sheltered ramp in contact with the ground on its underside, to 180 W/m^2 when the ramp is exposed on both sides.

Economics

When estimating the operating costs for road heating it must be borne in mind that during the heating-up period the temperature of the concrete around the cable has to be raised to about 6°C above the surface temperature to promote the necessary heat flow from the cable to the road surface.[5] The heat capacity of the concrete can be equal to several hours normal running, and failure to make due allowance for it could cause a noticeable error in running-cost calculations. It is this same heat capacity that is used to provide thermal storage in off-peak heating systems. For ramp heating the use of off-peak electricity is not necessarily the most economical solution as it involves storing heat in the concrete in case the air temperature drops below freezing point.

It is also well worth considering underslab heating when parking takes place on open roofs as driving on frozen snow at this height can prove a disturbing experience for someone not familiar with these conditions.

Ventilation

Ventilation is required in car parks to avoid the risk of fire and explosion arising from petrol fumes, and prevent injury to health from the toxic gases present in vehicle exhausts. Mechanical ventilation is expensive to provide, and it is therefore usual to use natural ventilation as much as possible. Natural ventilation is normally a feasible approach in multi-storey car parks and is acceptable under GLC regulations provided that permanent openings are provided in at least two walls and that the minimum free area of these ventilation openings is not less than $2\frac{1}{2}$ per cent of the garage floor area. (See Fig. 1)

With underground or enclosed car parks, however, air for the dilution of the products of combustion of motor-vehicle engines has to be provided mechanically. The problem therefore with this type of building is to keep the cost of the ventilation system down to a reasonable level while maintaining physiologically accept-

Table 1 Signs and symptoms at various concentrations of carboxy-haemoglobin[6]

%COH_{gb}	Signs and symptoms for an average man
0–10	No signs or symptoms
10–20	Tightness across the forehead, possible slight headache, dilation of the cutaneous blood-vessels
20–30	Headache and throbbing in the temples
30–40	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting and collapse
40–50	Same as 30–40, greater possibility of collapse, syncope and increased pulse and respiratory rates
50–60	Syncope, increased respiratory and pulse rates, coma, intermittent convulsions, and Cheyne-Stokes respiration
60–70	Coma, intermittent convulsions, depressed heart action and respiratory rate, and possible death
70–80	Weak pulse, slow respirations, respiratory failure and death within a few hours
80–90	Death in less than an hour
90+	Death within a few minutes

able conditions for the users. We must therefore first examine the exhaust gases, determine which constituents are toxic, and which of these constituents will be the governing factor in determining the air volumes to be handled by the ventilation system.

Products of combustion

Petrol and diesel oil are both hydrocarbon fuels and therefore produce oxides of hydrogen and carbon. In addition most petrols also contain 'anti-knock' agents that have lead among their constituents. As the oxidation of fuel in an internal-combustion engine is never complete, the products of combustion contain the following main compounds – carbon dioxide, carbon monoxide, water vapour, sulphur dioxide, oxides of nitrogen, unburnt fuel and lead compounds.

Of these main constituents only four are toxic – carbon monoxide, the oxides of nitrogen, sulphur dioxide and the lead compounds. The lead compounds are not normally present in sufficient quantities to make them as dangerous to health as the carbon monoxide (CO) and the oxides of nitrogen.

The toxic properties of carbon monoxide are created by its having a higher affinity for haemoglobin than oxygen and being preferentially absorbed by the haemoglobin in the blood-stream to form carboxy-haemoglobin.

Threshold levels

Schultz[6], in his investigation into the effects of CO on the metabolism, co-ordinated and tabulated the results of earlier workers in this field and produced Table 1, which correlates symptoms exhibited by subjects at different concentrations of carboxy-haemoglobin (COH_{gb}) in their blood-stream. The equilibrium level of COH_{gb} in the blood-stream varies with the concentration of CO present in the atmosphere, and the rate of CO absorption increases with the metabolic rate. The Road Research Laboratory[7] have co-ordinated these various parameters, and the results are given in Table 2. By reading Tables 1 and 2 together it is possible to obtain an indication of how long a person can tolerate a given CO concentration before he will exhibit adverse symptoms. The American Conference of Government Industrial Hygienists[8] (ACGIH) recommends that the maximum allowable concentration of CO for an eight-hour exposure should be limited to 50 ppm.

The oxides of nitrogen, NO and NO^2, are not as immediately obvious in the effects as carbon monoxide, but tests with laboratory animals have indicated that the direct effects are more permanent and can also reduce resistance to diseases. Nitrogen dioxide is the more toxic of the two and recommended threshold limit for an eight-hour exposure is 5 ppm.

The quantity of sulphur present in the fuel is about 0.1 per cent by weight in petrol and 0.35 per cent by weight with diesel fuels. The total volume of sulphur dioxide produced is not therefore very great.

Dilution rates

An assessment of the representative composition of exhaust gases is given in Table 3A[9], and these concentrations are combined with the ACGIH limit values to give a recommended dilution rate in Table 3B.

From Table 3B it can be seen that if we ignore smoke production, the petrol engine is by far the worst offender from the pollution point of view and that its most predominant pollutant is carbon monoxide. It follows therefore that any decision about ventilation rates for car parks must be closely related to the actual volume of carbon monoxide that will be liberated to the space by car engines as opposed to a volumetric analysis of the products of combustion. This requires a knowledge of the absolute quantity of CO liberated, and the results of some experimental work on this subject are given in Table 4.[10]

Effects of possible legislation

At this point it is probably worth examining the possibility of legislation being introduced which will partially alleviate the problem. At present there is no legislation existing in this country for the control of invisible emissions, and the *Motor Vehicles (Construction and Use) Regulations 1966* require that 'Every motor vehicle shall be so constructed that no avoidable smoke or visible vapour is emitted therefrom'. The United Kingdom is, however, one of the European countries that has produced harmonized standards for this problem. The probability is that legislation will be introduced in most of the contributory countries to make these recommendations mandatory. The exceptions are Germany and Sweden, who felt that the suggested limits are too lenient.

The reductions proposed are quite modest when compared with the US Federal Standards, which require that the carbon monoxide produced by a car engine should not exceed 14.5 g/km. The present CO emission of an average British car on the basis of the US Federal Test is about 42 g/km. Implementation of the European regulations will reduce the CO emission of an average British car to about the equivalent of 29 g/km. While the European proposals are not as stringent as the American ones, they do represent a reduction of 30 per cent in CO emission, and this will ultimately enable a similar reduction to be made in size of the ventilation installation.

As new legislation cannot always be made applicable to existing vehicles it may be several years after the introduction of new legislation before we can safely take advantage of the benefits it provides when we formulate our designs for related ventilations systems.

Amounts of CO

Table 4 shows that on average a five-passenger car will produce 1.7 m^3 of carbon monoxide per hour. If we work on the basis of limiting the average concentration in the car park to the ACGIH recommendation of 50 ppm with peak levels of 100 ppm for short periods, this means that we will require a ventilation rate of 8.2 m^3/s of fresh air per car in average conditions, with absolute minimum of 4.1 m^3/s. A car park is normally designed so that at peak parking times it will be full. Car engines, however, normally operate only for a small percentage of the time they spend in a car park, and in order

Table 2 Carboxy-haemoglobin content of blood (in terms of percentage full absorption) for different concentrations of carbon monoxide in the atmosphere[7]

Concentration of CO in the atmosphere (ppm)	Equilibrium of COH_{Gb} in the blood (%)	COH_{gb} in the blood after 30 min exposure (%)		COH_{gb} in the blood after 60 min exposure (%)	
		Rest	Heavy work	Rest	Heavy work
30	4.8	0.27	0.99	0.54	1.98
50	8.0	0.45	1.65	0.90	3.30
125	20	1.12	4.12	2.24	8.24
250	40	2.25	8.24	4.50	16.48

Table 3A Representative composition of exhaust gases (concentrations in parts per million by volume)

	Pollutant	Idling	Accelerating	Cruising	Deceleration
Petrol engines	Carbon monoxide	69,000	29,000	27,000	39,000
	Hydrocarbons	5300	1600	1000	10,000
	Nitrogen oxides	30	1020	650	20
	Aldehydes	30	20	10	290
Diesel engines	Carbon monoxide	trace	1000	trace	trace
	Hydrocarbons	400	200	100	300
	Nitrogen oxides	60	350	240	30
	Aldehydes	10	20	10	30

Table 3B Dilution rates required in various conditions

	Pollutant	Idling	Accelerating	Cruising	Deceleration
Petrol engines	Carbon monoxide	690	290	270	390
	Hydrocarbons	27	8	5	50
	Nitrogen oxides	6	204	130	4
	Aldehydes	6	4	2	58
Diesel engines	Carbon monoxide	–	10	–	–
	Hydrocarbons	2	1	0.5	1.5
	Nitrogen oxides	12	70	48	6
	Aldehydes	2	4	2	6

Table 4 Quantity of carbon monoxide emitted per car per hour[10]

Type of vehicle	Mean of light and full load Minimum	Maximum	Average	Full load only Minimum	Maximum	Average
	m^3	m^3	m^3	m^3	m^3	m^3
Five-passenger car	0.82	2.18	1.47	–	–	–
Seven-passenger car	1.19	4.08	2.52	1.10	4.64	2.78
Truck up to 1½ ton	0.87	2.72	1.73	1.05	3.34	1.89
Truck 1½–3 ton	0.42	3.82	2.24	0.68	4.24	2.58
Truck 3½–4 ton	1.56	5.21	3.37	1.42	5.16	3.23
Truck 5 ton and over	1.44	5.15	3.14	1.33	5.64	3.65
Average	1.05	3.85	2.41	1.13	4.59	2.83

to obtain reasonably accurate information on this subject, the Detroit Bureau of Industrial Hygiene sponsored some work in this field.[11]

This investigation determined that the number of vehicle engines operating simultaneously was on average 1.23 per cent of the total capacity with short peaks of 3.5 per cent of the total capacity. This means that the air volume required per car will be:

$$\text{average} \quad \frac{8.2 \times 1.23}{100} = 0.1022\ m^3/s$$

$$\text{peak} \quad \frac{4.1 \times 3.5}{100} = 0.1435\ m^3/s$$

To keep the maximum concentration of CO within the permitted limit will therefore require a ventilation rate of about $0.14\ m^3/s$ per vehicle.

The entrance and exit areas are where the largest concentrations of traffic occur, but as the cars and their occupants are in the vicinity only for a short time it should be acceptable if they are designed for higher concentrations of carbon monoxide than the general car-park area and a figure in the region of 250 ppm of CO as would be used for a road-tunnel design should prove acceptable. If we limit ourselves to maintaining this higher figure, the air volume required per vehicle will reduce in the entrance and exit areas where engines run continuously from $8.2\ m^3/s$ to 1.66 m.

Pay booths

In the case of an attended car park this still leaves the problem of pay-booth attendants have to spend all their time in the most highly contaminated area of the car park. The simple answer is to pressurize the booth with a supply of fresh air that can be warmed in winter and ensure that the direction of leakage is from the booth to the traffic zone.

This technique has been used quite successfully for some time, albeit in the reverse direction with fume-cupboard extract systems, and should prove quite effective.

Comparison with USA

It is of interest to compare the recommenda-

Table 5A Recommendations for car park ventilation

Area	Ventilation l/s per car	Approximate air changes per hour
Car park area		
heavy usage	141	7.5
light usage	101	5.4
Entrance and exit	1650	68.5

Table 5B Statutory requirements for car park ventilation

Legislative body	Requirement air changes per hour	
New York City Code	4	
New York State Code	6	
US National Building Code	$6\frac{2}{3}$	5.07 l/s per m^2
Chicago Ventilation Code	$6\frac{2}{3}$	5.07 l/s per m^2
GLC Regulations		
light usage	3	
heavy usage	6	

tions developed in this paper with the different statutory requirements that are enforced both here and in the USA. Most statutory requirements are based on air change rates or, at best, air change rates per unit floor area. These methods are rather unsatisfactory as they base the ventilation rate on a volume of space and not on contaminant dilution. An average engine capacity in the USA is not however, the same as it is in the United Kingdom, and it would be wrong to view the recommendations developed here out of context. Table 4 gives the average CO emission as 1.4 m^3/h for a five-passenger car. A suitable allowance would have to be made if the average vehicle size in the car park was to be larger than the UK average.

The main requirements governing the mechanical ventilation of underground garages in the London Area are laid down in Appendix B :Part II of the Greater London Council Code of Practice[12] as follows:

'B2.05 Ventilation

1 Wherever practicable all basement garages should be provided with natural ventilation by means of openings positioned to induce cross-currents and having a total area of not less than $2\frac{1}{2}$ per cent of the area of the floor. Entrances may be included as providing part of this ventilation when closed only by lattice-type gates, and any such gates, shutters or doors to entrances should be locked shut only by means of a padlock fastening such as can be easily broken by a fireman in an emergency.

2 In addition to natural ventilation, mechanical ventilation should be provided independent of any ventilating plant for other parts of the building. Where natural ventilation to the full standard described in 1 foregoing is provided, it will usually be sufficient for the mechanical ventilation to provide for three changes of air per hour.

3 Where natural ventilation to the standard of 1 foregoing cannot be provided, the mechanical ventilation will be required to overcome the worst conditions likely to arise from the discharge of exhaust gases. The plant will need to be arranged so that it can be run in two equal parts, each capable of providing not less than three changes of air per hour when run separately, and so controlled that in the event of failure of one part the other part continues to function. A secondary source of electrical supply (or other suitable source of power) should be provided to ensure that one part of the ventilation plant continues to function in the event of a failure occurring in the principal source of supply. When the plant is not controlled automatically it will be required that a competent person be in constant attendance to supervise the plant.

4 Ventilating ducts should be constructed of non-combustible materials and where adjacent to or passing through other parts of the building the ducts should be constructed or protected so as to afford the same standard of fire-resistance as required for the separation of the garage under item B2.01 of this Appendix.'

The principal requirement here is that, when used, a mechanical ventilation system shall provide six air changes per hour. In Table 5A the ventilation rates per car developed in this paper are converted to approximate air-change rates for comparison purposes, and in Table 5B various statutory requirements for car park ventilation[12, 13] are listed.

Recommendations for ventilation design

The following suggestions are made in connection with car park ventilation design:

1 Ventilation rates for car parks should be based on the dilution of the carbon monoxide produced in them. This would avoid penalizing car parks with large volume/car ratios and would ensure that car parks with low volume/car ratios are adequately ventilated. The ventilation system should be designed so that the carbon monoxide level is normally 50 ppm and does not exceed 100 ppm during peak traffic periods.

2 Entrance and exit tunnels (when necessary) should be kept as short as possible so that the movement of cars will create adequate ventilation. Their relation to ticket machines and pay booths should be such that cars are not forced to queue in confined spaces unnecessarily.

3 When possible the pay booths should be located in the open air and not in a confined space.

4 The system should be designed so that two plants each handle half the required extract volume, and a standby generator should be provided for one plant. The standby generator should be able to supply either plant. A suitable air supply should be arranged to the generator plant room for fuel combustion, engine cooling and the general ventilation system.

5 If there are toilets at the garage level without direct access for fresh air, a supply and extract system will be required for them on the usual lines for internal lavatories.

6 Fresh-air intakes should be arranged so that they draw in clean air. If the air is already polluted the ventilation rate will have to be adjusted accordingly. In some instances the only way to ensure unpolluted air will be to situate the fresh-air intake at roof level.

7 Traffic arrangements should be checked. If cars have to travel through the lower levels of the car park to reach the higher ones, an allowance may have to be made in the design of the ventilation system.

These suggestions should provide a ventilation system at the most economic price commensurate with the provision of satisfactory environmental conditions.

Road-tunnel ventilation

A point worth mentioning in passing is that during the preparation of this paper it became obvious that the majority of the basic information being used was equally applicable to road tunnel ventilation design and could have repercussions on the cost of road tunnel ventilation.

It is current practice with road tunnels to design for a carbon monoxide concentration of 250 ppm. This figure assumes that the car occupants will be subjected to this concentration of CO only for a very short period. The tendency at the moment seems to be towards longer road tunnels with the result that cars will remain in the tunnel for a longer period. Schultz[6] and Beard and Wertheim[14] indicate a clearly discernable drop off in human performance with only 5 per cent COH_{gb} present in the blood-stream. The permissible concentration of CO in the tunnel must therefore reduce as the tunnel length increases. This means that the cost of ventilating long road tunnels will rise out of all proportion to the length of the tunnel.

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Blackheath Meeting House

Edmund Happold
Ian Liddell

The Congregationalist church in Blackheath was bombed during the war. Its rebuilding after the war was one of the first designs completed by Trevor Dannatt after he had set up in his own practice. The church hall, however, remained and was used for Sunday School, church socials and by the Blackheath Meeting of the Society of Friends. The latter arrangement was temporary but when the Meeting wished to build a Meeting House the Church made available a small piece of land, which was the previous turning circle at the end of a private road (Independants Road) with the two-storey hall on the north side and an upper level road (Lawn Terrace) on the south side.

The brief was to provide a hall to seat 100 people, two committee rooms, a kitchen, lavatory accommodation and a link to the existing church hall at ground level. A town planning requirement was to allow space for parking four cars and this, together with the considerable change in level between Lawn Terrace and the site ground level, made it sensible for the pedestrian entrance to be off Lawn Terrace at the upper level into an entrance hall and tea kitchen at the Meeting Hall. Stairs then lead down to the ancillary accommodation, the car parking and the link to the church hall.

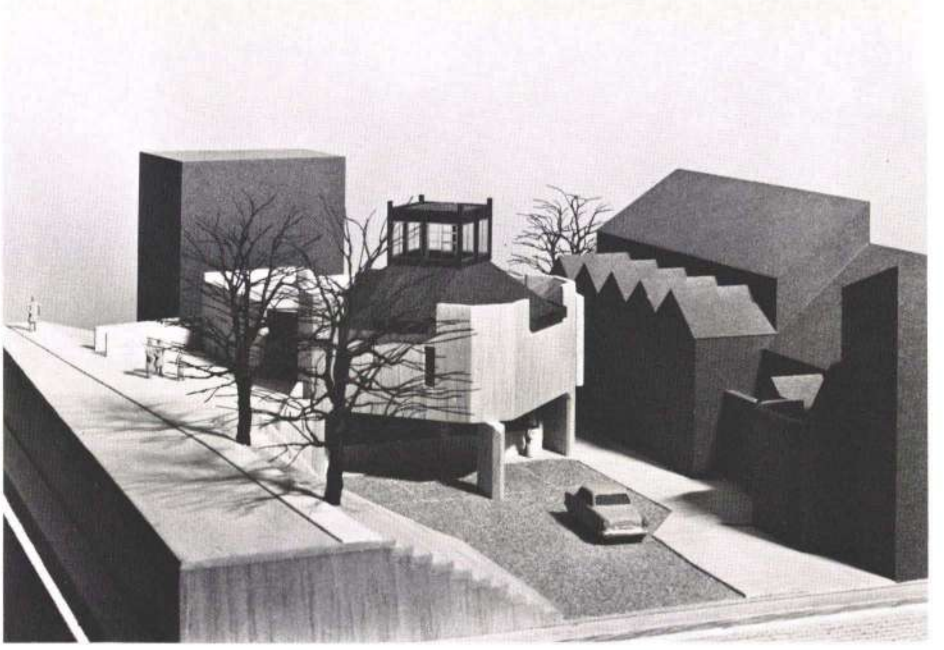


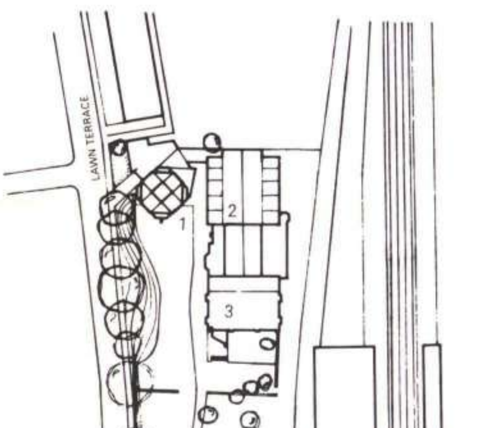
Fig. 2

Model showing relationship to surrounding buildings and roadway

Fig. 3

View showing car park and link to the church hall on the right

Trevor Dannatt first considered a square plan for the main space parallel with the church hall but decided to rotate it 45° to avoid a feeling of congestion against the existing building and to isolate the new building. From this originated the entrance hall, an important space in the social life of the Meeting, with stepped walls in plan, a stepped ceiling and leading to the calm space of the hall. At a meeting Friends sit round in a square and he felt that natural light from above, provided by a central lantern, was

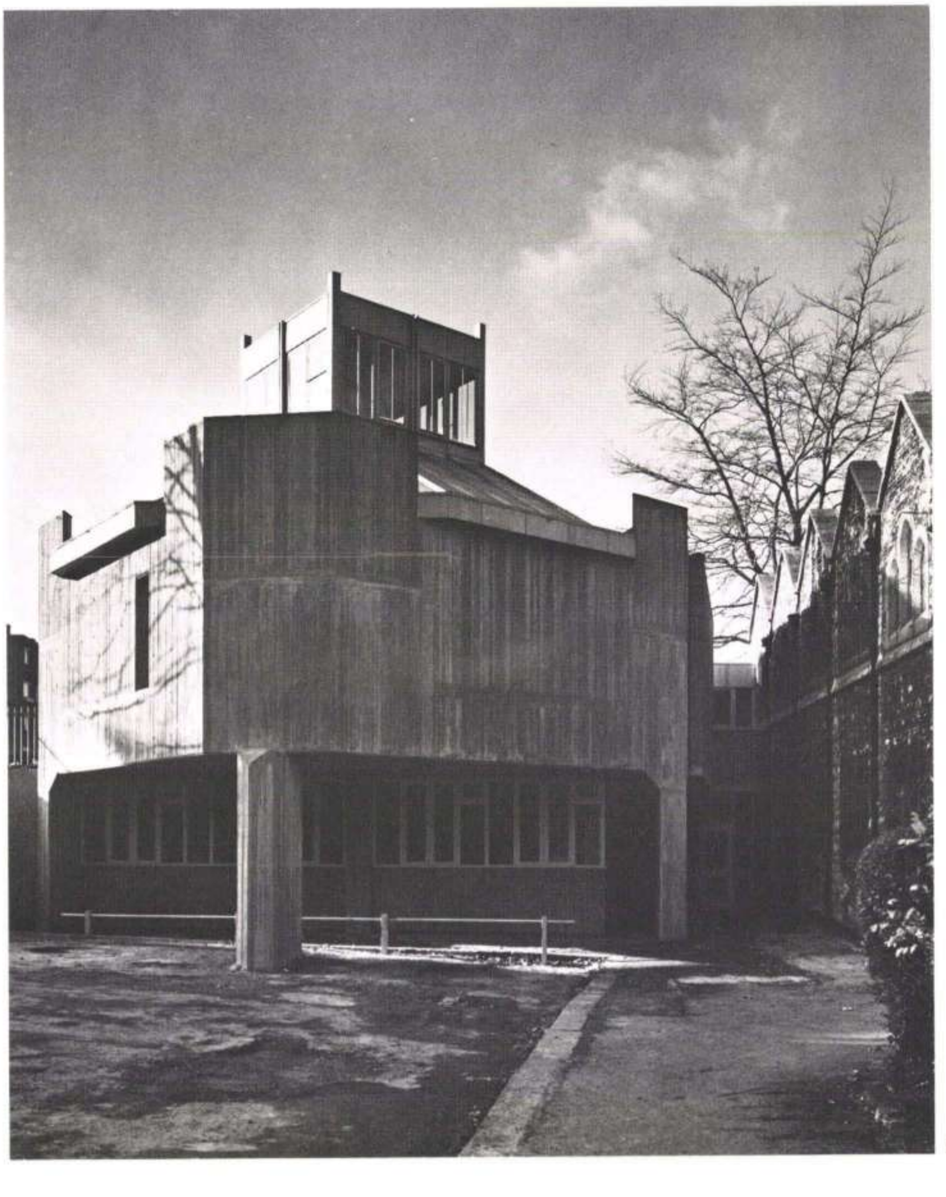


Key

1 Meeting House
2 Church Hall
3 Congregational Church
4 Station

Fig. 1

Location plan



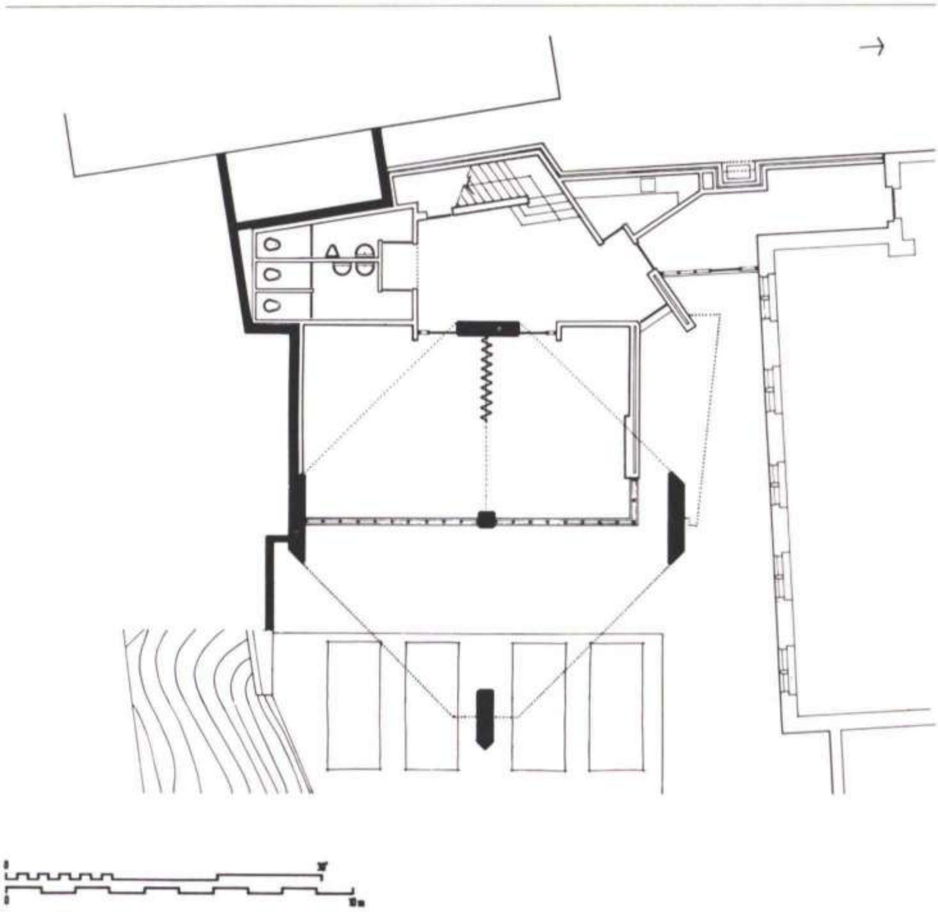
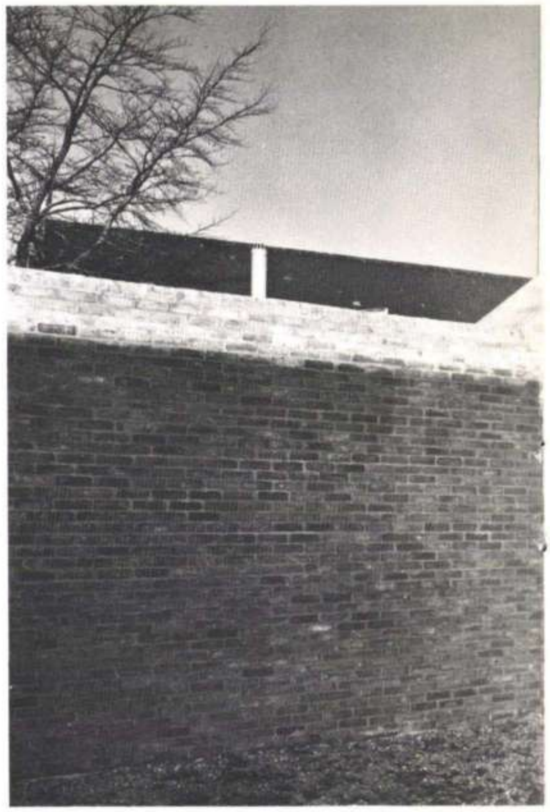


Fig. 4
Lower floor plan



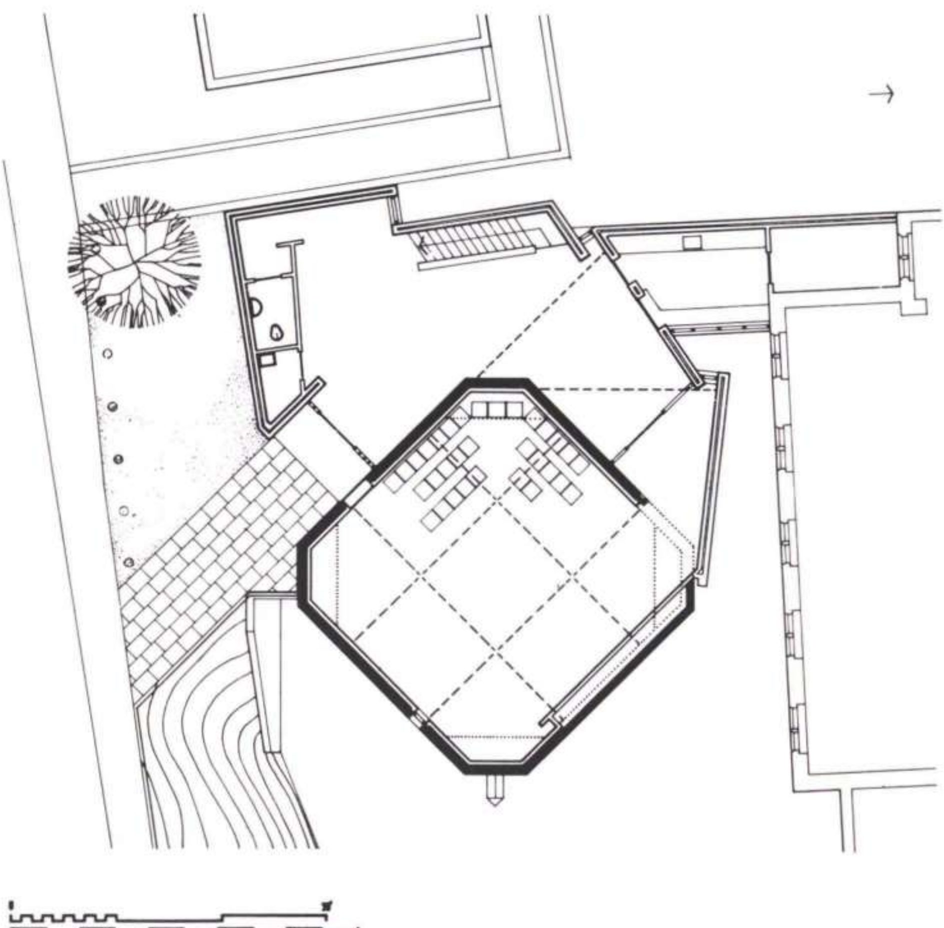


Fig. 5
Upper floor plan

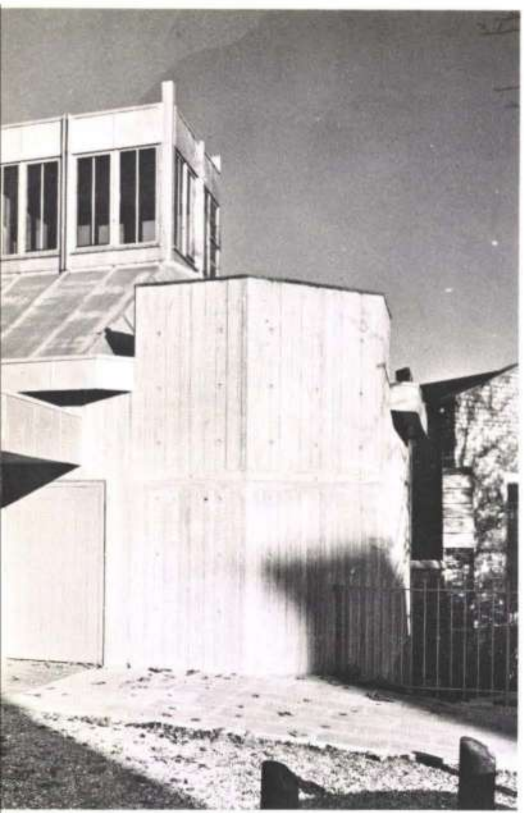
appropriate. The corners of the room are cut off, leaving space between roof and outside wall which is glazed to provide natural lighting on the wall surface. The walls at the corners are carried up externally as turrets to receive the top of the glazing.

Structurally, Blackheath Meeting House is similar in concept to Bootham School, York (Job no. 1753). The walls of the hall act as beams to support the floor and simple deep trusses span onto the walls to support the roof. At Blackheath the span of the roof was such that the trusses could be made of timber for the compression and bending members with steel ties. It was felt that this form of construction gave a suitable internal appearance and could be built with a few special joints by carpenters.

Two trusses span in two directions intersecting at four vertical members which extend above the roof level to support the lantern. The joints are formed with steel brackets which bolt to the vertical member and have a vertical tongue. The timber members are formed from a pair of 250 × 50 mm timbers which bolt onto the tongue with shear plate connectors forming a pinned joint.

Under symmetrical loads this arrangement is stable without cross-ties in the central bays and Trevor Dannatt wished to avoid these. For unsymmetrical loads it is a mechanism with one degree of freedom which can be adequately restrained by horizontal cross-ties at the level of the truss compression members.

The walls of the Meeting House are designed as concrete beams to reduce the floor depth and to carry the load from the roof to the four corner columns. They are exposed externally with a boarded finish. A column stands under the centre of the floor to reduce the span of the flat slab. To allow for existing services and basements the foundations had to be offset under two of the columns, but the 'box' design accommodates the additional forces produced. The cost was £37,842 which worked out at £12.64 per ft^2. Bill Upton was the services consultant, Monk and Dunstone were the quantity surveyors and certainly earned their fee because the first contractor appointed started on site and then calmly announced he would not continue. Litigation on that scale of contract being senseless, and a lot of talking getting nowhere, we negotiated with the next lowest tenderer, R. Mansell Ltd., who did an excellent job.



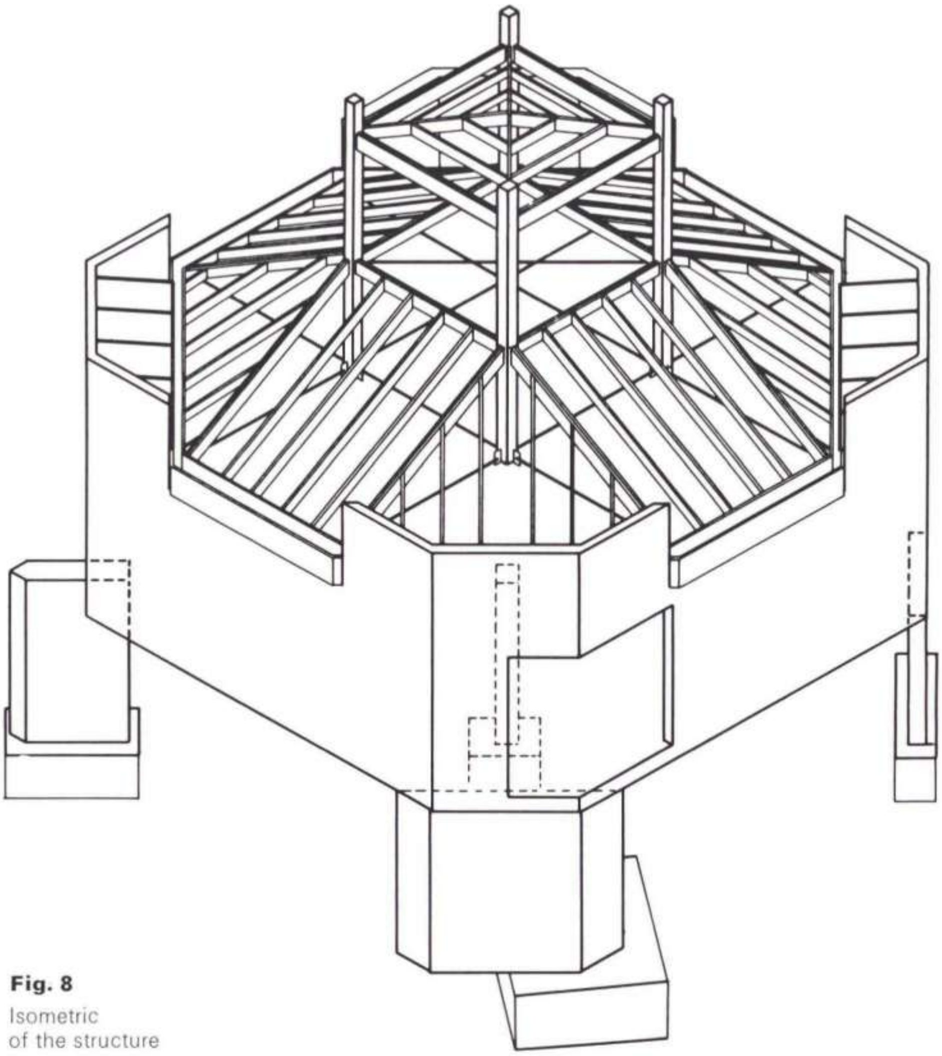


Fig. 6
Pedestrian entrance off Lawn Terrace

(Photos reproduced in this article by courtesy of the architects)

Fig. 7
Roof structure showing lantern and steel ties

Fig. 8
Isometric of the structure

Field instrumentation for long-term measurement of pile load and raft contact pressure

John Hooper

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Introduction

Although piled rafts are commonly used to support tall buildings on a variety of soil strata, the general complexity of this type of foundation gives rise to numerous design problems. Most of these centre around the apportionment of applied building load between the piles and the underside of the raft, both during and after construction. This load sharing depends in turn upon the stiffness and plan shape of the foundation, as well as on soil properties.

With these problems in mind, the opportunity was taken in the summer of 1967 to install load-measuring instruments into the foundations of the main tower block of the Hyde Park Cavalry Barracks in central London. In this case, the piled-raft foundation of the 90 m high building is embedded in a thick clay layer, and comprises 51 concentrically arranged concrete piles (910 mm diameter, 25 m long) capped by a 1.52 m thick reinforced concrete raft in contact with the clay. Load cells of 6000 kN capacity were installed in three of the piles located on a radial line, and three earth pressure cells were installed to measure the contact pressure at the raft-soil interface. Load cell readings and related numerical analyses are to be published separately, but details of the instrumentation are given herein.

Field measurements of the sort required in such an investigation are patently difficult to obtain, due mainly to the combination of arduous site conditions and the necessity of recording loads over a long period of time. Clearly any instrumentation used for this type of work must be robust and have excellent long-term stability, yet the available range of instruments which meet these requirements is severely limited; it is well-known, for example, that load gauge systems based upon resistance foil or vibrating wire gauges have a definite tendency to be troublesome when used in long-term field applications. Experience with photoelastic load gauges[1], however, has shown them to meet the above requirements, and gauges of this type were considered to be the most suitable for the present investigation. They do have the disadvantage that visual access is required for the purpose of taking gauge readings but, as in the present case, these difficulties can usually be overcome.

The fundamental aspects concerning photoelastic load gauges have been dealt with elsewhere[2], and so the account which follows relates only to the application and extension of the basic load-measuring system to a form suitable for measuring pile loads and earth pressures. A description is therefore given of the design and construction of the two cells, and also of the ancillary polarized light unit. In connection with the earth pressure cell design, an assessment is made of the effect of overall cell stiffness on measured cell pressures by means of the finite element method.

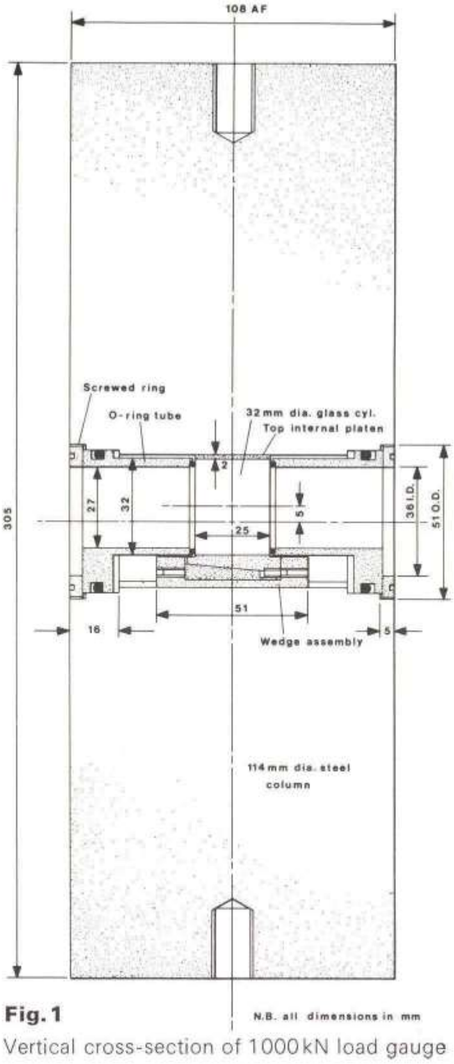

Fig. 1

Vertical cross-section of 1000 kN load gauge

Pile load cell

Design of 1000 kN load gauge

At the design stage of the building it was anticipated that the maximum load to be taken at the top of any of the piles within the group was approximately 6000 kN. However, from various practical considerations, the maximum load-carrying capacity of a single photoelastic gauge is in the region of 1000 to 1500 kN. In order to measure higher loads, it is necessary to construct a cell which incorporates a number of such gauges and, for the pile load cell, the 1000 kN column-type load gauge was used as the basic load-measuring device.

The principal components of the 1000 kN load gauge are shown in Fig. 1. The basic load-carrying element is a 114 mm diameter, 305 mm long, steel column with a 41 mm diameter transverse hole at mid-height. A solid glass cylinder is located at the centre of the hole and is pre-loaded across a diameter by means of a wedge mechanism. The transverse hole is slotted in order to provide a flat seating for the wedge cradle and top internal platen; it is also counterbored at each end so as to receive the O-ring sealing tubes. These cadmium-plated tubes form a secondary defence against corrosion; for primary protection, the transverse hole is chromium plated and the internal platens and wedges are made in stainless steel.

The operating principle of the gauge is that load applied at the ends of the column causes deformation of the transverse hole which, in turn, compresses the glass cylinder across a diameter. If circularly polarized light is then passed through the glass cylinder, and the latter viewed through an analyzer, the isochromatic fringe pattern in the glass becomes directly visible. This pattern has a characteristic shape and readily allows the fringe order at the centre of the cylinder to be measured. By this means, a direct relationship between the applied load and the fringe order in the glass transducer can be established. Such a relationship is normally computed for design purposes; after manufacture, exact values are determined by calibration.

A typical calibration curve for a 1000 kN load gauge is shown in Fig. 2. In this example, the glass cylinder pre-load was set at 0.5 fringe, and the fringe readings themselves relate to a red filter having a predominant wavelength (λ) of 645nm. The slight curvature of the calibration line is a direct consequence of the non-linear displacement mode of an elastic circular cylinder compressed across a diameter between flat platens. In general, load gauges are designed to read approximately five fringes at maximum working load; this also ensures that the load carried by the glass cylinder itself is sufficiently small in magnitude compared with the strength of the cylinder in diametral compression[3].

In practice, there are small but noticeable differences between the calibration curves of a number of similar gauges. In the present investigation, in which 18 individual gauges were used, readings at maximum working load were within ± 0.25 fringe of the mean value. Hence, for accurate work, each gauge is provided with its own calibration curve. A further practical consideration concerns the influence of ambient temperature on gauge readings. Although the response of photoelastic load gauges is relatively insensitive to temperature changes, small corrections to field measurements are necessary for accurate determination of applied load. In this connection, a typical temperature correction curve is shown in Fig. 3.

Basic construction of pile load cells

In its basic construction, the pile load cell consists of six 1000 kN column-type load gauges confined between two circular steel end plates, as indicated in Fig. 4. The load gauge columns

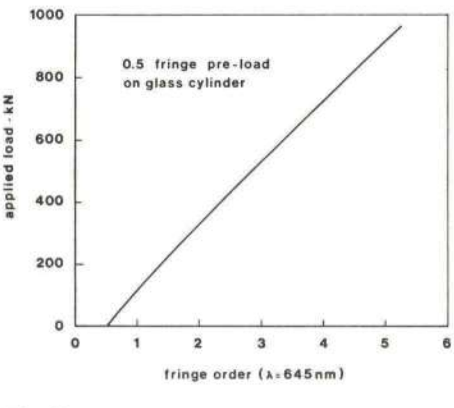

Fig. 2

Typical calibration curve for 1000 kN column-type load gauge

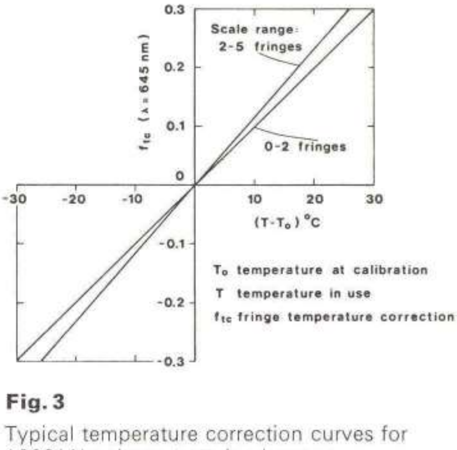

Fig. 3

Typical temperature correction curves for 1000 kN column-type load gauge are connected to the end plates by means of 13mm diameter socket screws. The end plates themselves, which are 57 mm thick, have an external diameter of 875 mm, which allowed the use of standard 910mm diameter pile shuttering during installation of the cells. A standard pipe flange is bolted on to the lower plate to help key the cell into the mortar bed. A 152mm diameter concentric hole in the upper plate allows entry of the portable light unit; access to the cell is by means of a 152 mm diameter, 3m long, steel tube passing through the concrete to the top of the raft.

The relative positions of the load gauges were chosen so as to minimize the bending stresses in the end plates. In this connection, Yu and Pan[4] have derived analytical expressions for the deflections of a uniformly-loaded circular plate (radius R), supported at three equally-spaced points along the circumference of a concentric circle. This analysis shows that plate deflections are a minimum if the supports are located along a concentric circle having a radius of between $0.61R$ and $0.65R$. It is reasonable to assume that this range is also applicable to the case of six equally spaced gauges, particularly in view of the fact that the centroid of a 60° sector of a circle lies at a radius of $0.637R$ from the apex. Accordingly, the six gauges were equally spaced at a radius of 280 mm. With this configuration, the computed maximum bending stresses were low enough to permit the use of mild steel for the 57 mm thick end plates.

To prevent corrosion of the access tube, the internal bore was coated with an epoxy resin (*Ensecote AV*). For internal protection of the cell, the columns and inner plate surfaces were coated with a similar epoxy resin (*Peridite PS 3848*). The outer plate surfaces were coated with red-lead paint. The periphery of the cell was sealed by a double layer of aluminium and rubber sheeting, the purpose of the aluminium being to act as a support for the rubber seal. The 370mm-wide aluminium band was fixed to the plates using an epoxy resin cement (CIBA resin *AV121*, hardener *HY951*), followed by a 406 mm wide, 1.6 mm thick, strip of neoprene rubber. Both aluminium and rubber strips were held in position during and after initial fixing by stainless steel binders.

Assembly of pile load cells

An important design consideration for this type of load cell concerns the method of connecting the individual load gauges to the end plates. In the cells described by Whitaker[5], for example, the strain-gauged pillars were welded to the plates in order to provide the necessary end fixity. In the present case, however, the gauges were attached to the plates using simple screwed connections. The overriding advantage of this latter approach is that it enables the individual load gauges to be fully proof-loaded and calibrated prior to final assembly of the pile load cell, and even removes the necessity of calibrating the assembled cell.

Clearly, for this method of connection to be of use, the lack of fit between the gauge columns and end plates must be minimized. Accordingly, the inner face of each end plate was ground flat, and the end faces of each set of six gauges were ground together to give a uniform column length. During assembly of the cells, the lack of fit between the upper plate and each gauge column was determined using standard feeler gauges. Results for the three cells prior to fixing the upper plates are given in Fig. 5. When the socket screws were hand-tightened using a standard wrench with a short extension piece (Fig. 6), the lack of fit reduced to zero in all cases. It was therefore anticipated that residual loads in the gauges were of negligible proportions, and that the application of a concentric load to the cell would give approximately the same load in each gauge.

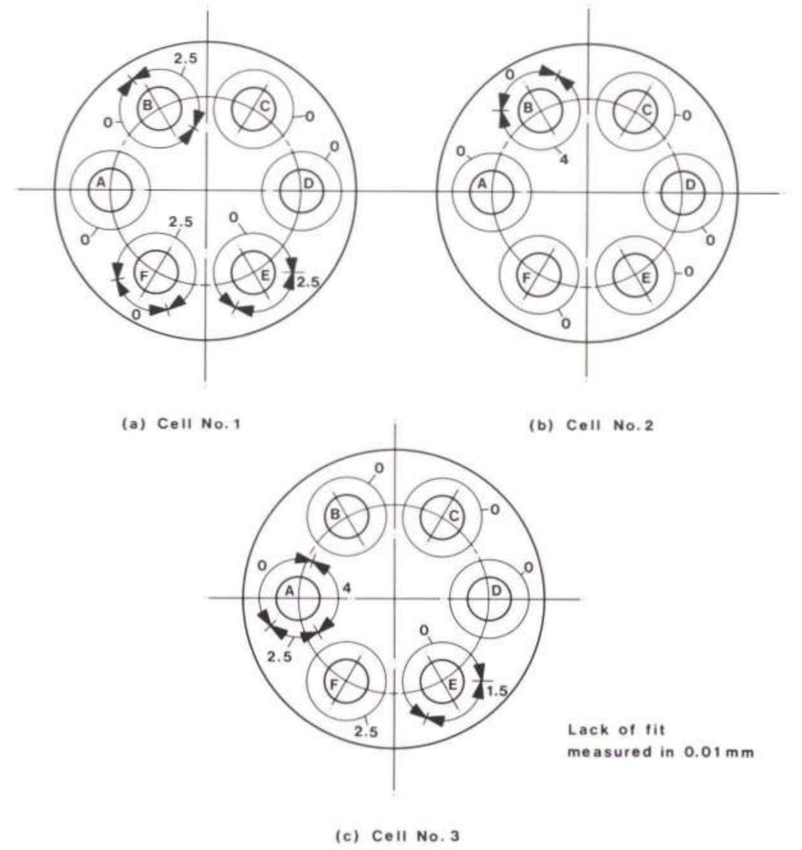

Fig. 5

Lack of fit between gauge columns and end plates of pile load cells prior to fixing

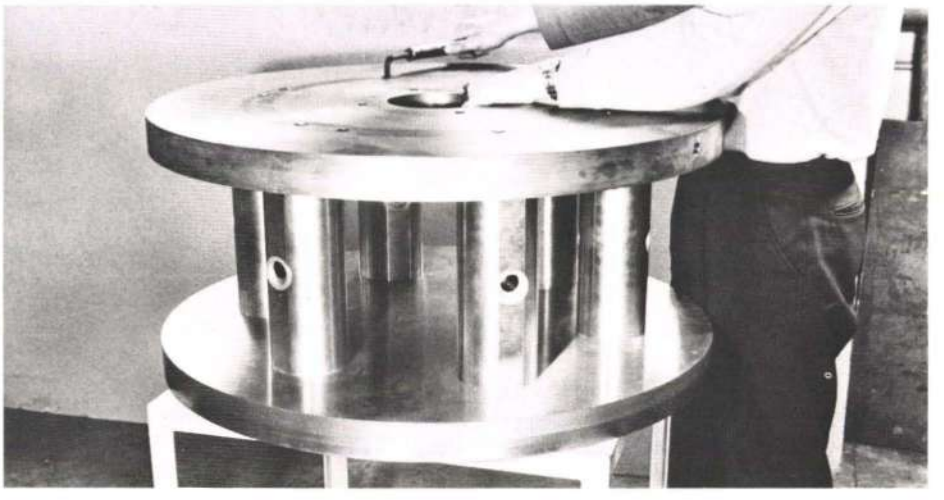

Fig. 6

Assembly of 6000kN pile load cell

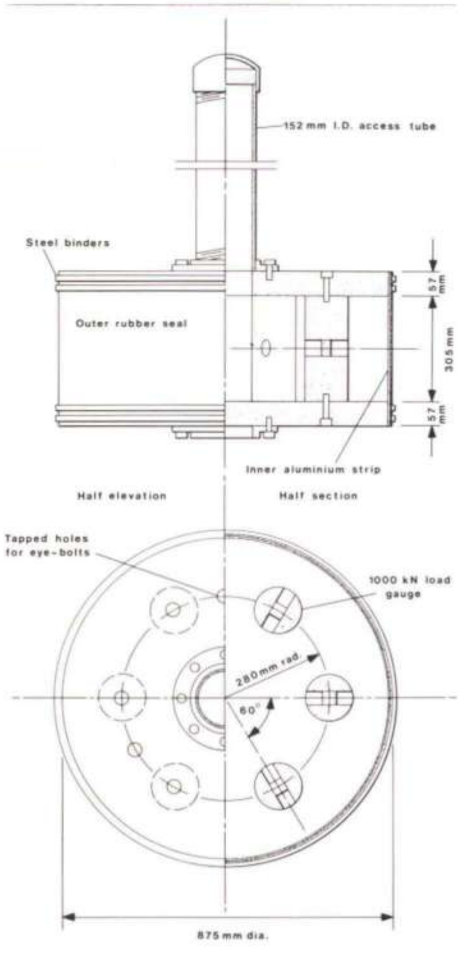

Fig. 4

Constructional details of 6000 kN pile load cell

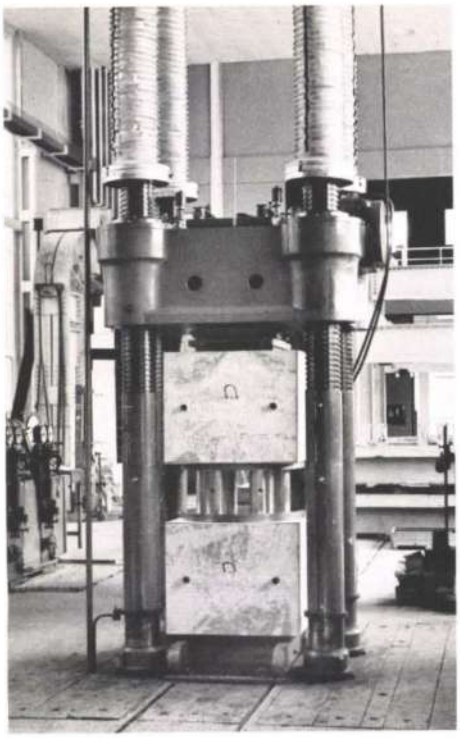

Fig. 7
Calibration of 6000 kN pile load cell

Calibration of pile load cells
As these load cells were the first of their kind to be built, it was considered prudent to check the predicted sensitivity and overall behaviour of the assembled units. On this basis, the cells were calibrated in the 10 MN Amsler testing machine at the Building Reseach Establishment (Fig. 7).

Two blocks of reinforced concrete (900 mm cube) acted as loading platens, and plywood sheets were interposed between each block and end plate. Initially, 3 mm thick sheets were used, but these gave rise to a markedly non-uniform load distribution. Subsequent examination of the concrete blocks revealed that the faces were slightly concave, presumably due to differential shrinkage. This concavity, which amounted to 1.6 mm at the centre of each face, was also reflected in the uneven impressions left on the plywood packing pieces. Thicker plywood layers were therefore tried, and it was not until the total thickness was increased to 38 mm that an even load distribution was obtained.

Prior to calibration, each cell was twice loaded fairly rapidly to 6000 kN for the purpose of bedding-in the external platens. Load was then applied in increments of 600 kN, and fringe order readings taken for each gauge in turn. The results were most satisfactory in that, for each cell, the total maximum applied load deduced from individual load gauges was within ± 2 per cent of the corresponding load indicated by the testing machine. In addition, individual load gauge readings were within ± 2 per cent of the mean value at maximum applied load.

During calibration of one of the cells, the mutual approach of the two end plates was measured using a dial gauge placed close to one of the gauge columns. At 6000 kN, the measured displacement was 0.21 mm, which is close to the computed value. Ideally, the overall axial deformation of the load cell should be equal to the corresponding change in length of the section of concrete pile it replaces. In the present case, this pile deformation amounts to 0.28 mm, assuming a Young's modulus of 13.8 kN/mm^2 for the concrete. As a result of this close agreement between the stiffness of the cell and its equivalent volume of concrete, the presence of the cell should have virtually no effect upon the load distribution in the pile.

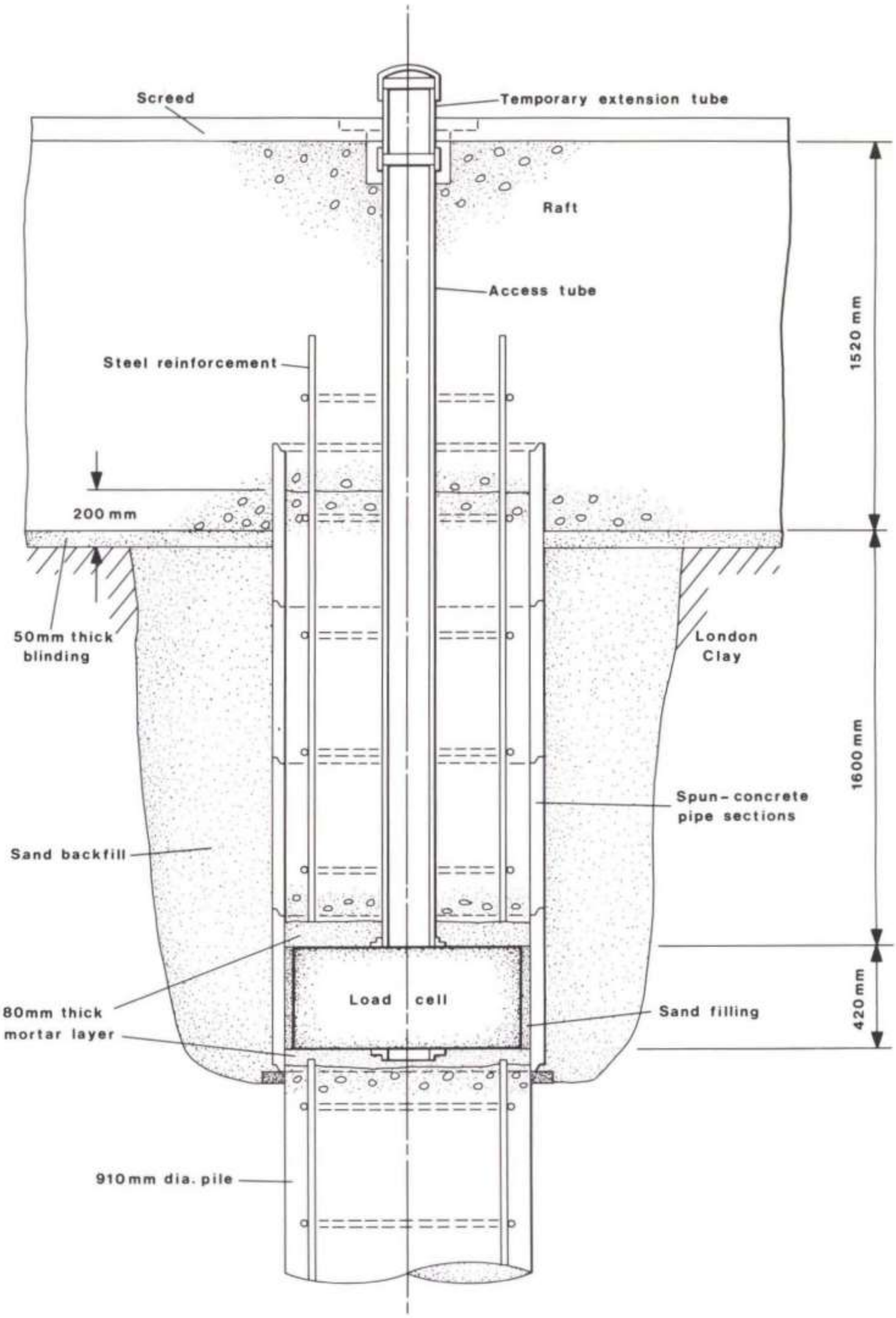

Fig. 8
Location of load cell in piled-raft foundation

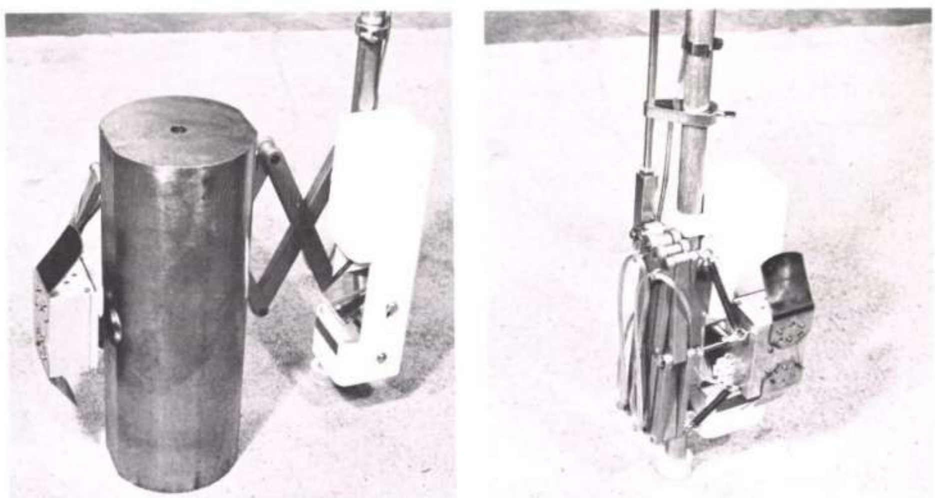

Fig. 9
Two views of portable polarized light unit

Installation of pile load cells

The location of one of the load cells within the piled-raft foundation is shown in Fig. 8. The concrete pile was first broken down to the correct level, and a 610 mm wide section of 910 mm diameter spun concrete pipe placed on blocks level with the pile top and aligned concentrically with the pile. An 80 mm thick bed of mortar was placed on top of the pile and the cell lowered into position. The annular cavity between the pipe and load cell was filled with sand, and extra pipe sections built up to act as permanent shuttering. The steel access tube was then lowered and bolted in position, and the joint sealed with silicone rubber.

With the access tube fixed in position, an 80 mm thick layer of mortar was placed on top of the cell and left overnight to set. At the same time, the cavity around the pile shuttering was backfilled with sand, which was well compacted in 0.3 m layers. The remaining pile section was then formed, the concrete being cast to a level just above the blinding layer. Several days later, the steel reinforcement for the raft was laid out, and the concrete poured to a thickness of 1.52 m.

Portable polarized light unit

With the pile cells in place, fringe patterns in the glass transducers are viewed by means of the portable polarized light unit (Fig. 9). The slotted, square-section steel tube houses an adjustable inclined mirror and is fastened to a short length of steel pipe. Attached to the side of the tube is one arm of a lazy-tongs mechanism, the adjacent arm of which is connected to the end of a short steel rod. Vertical movement of this rod therefore causes the linkage to extend or retract as required. With the aid of extension rods and tubes, the linkage can be operated from the raft surface.

A small aluminium box containing three 12 V, 2.2 W, light bulbs is fixed to a horizontal spindle located at the closed end of the lazy-tongs. Also built in to the light box is a combined polarizer and quarter-wave plate, together with a diffusing screen. It should be noted here that the presence of the mirror in the polariscope system has the effect of optically rotating the incident beam of circularly polarized light by 180°; hence care is required in the initial orientation of the light box polarizer in order to ensure conformity with the standardized fringe order measuring system[2].

In practice, load gauge readings are taken by lowering the retracted light unit down the access tube until contact is made with the bottom plate surface. The lazy-tongs are then extended by depressing the vertical control rod, and the light box positioned at the back of one of the gauges. The fringe order can then be determined at the raft surface by observing the fringe pattern visible in the mirror through a portable analyzer or hand-viewer. This procedure is followed for each gauge in turn. In the present case, the distance of approximately 3.7 m between load gauge and observer represents just about the maximum distance at which fringe readings can be taken with the naked eye; where possible, a telescopic attachment should be used in conjunction with the analyzer if the viewing distance is greater than about 3 m.

Earth pressure cell

Design of 100 kN load gauge

Based upon a maximum anticipated contact pressure of 250 kN/m² between the raft and soil, and a proposed cell diameter of 685 mm, a load gauge of 100 kN capacity was required for each earth pressure cell. Details of this ring-type photoelastic gauge are given in Fig. 10. The ring itself is 89 mm wide, and the internal and external diameters are 41 mm and 76 mm respectively. The internal gauge components are very similar to those already shown (Fig. 1) for the 1000 kN column-type load gauge.

For the purposes of constructing the earth pressure cell, the ring gauge is loaded through

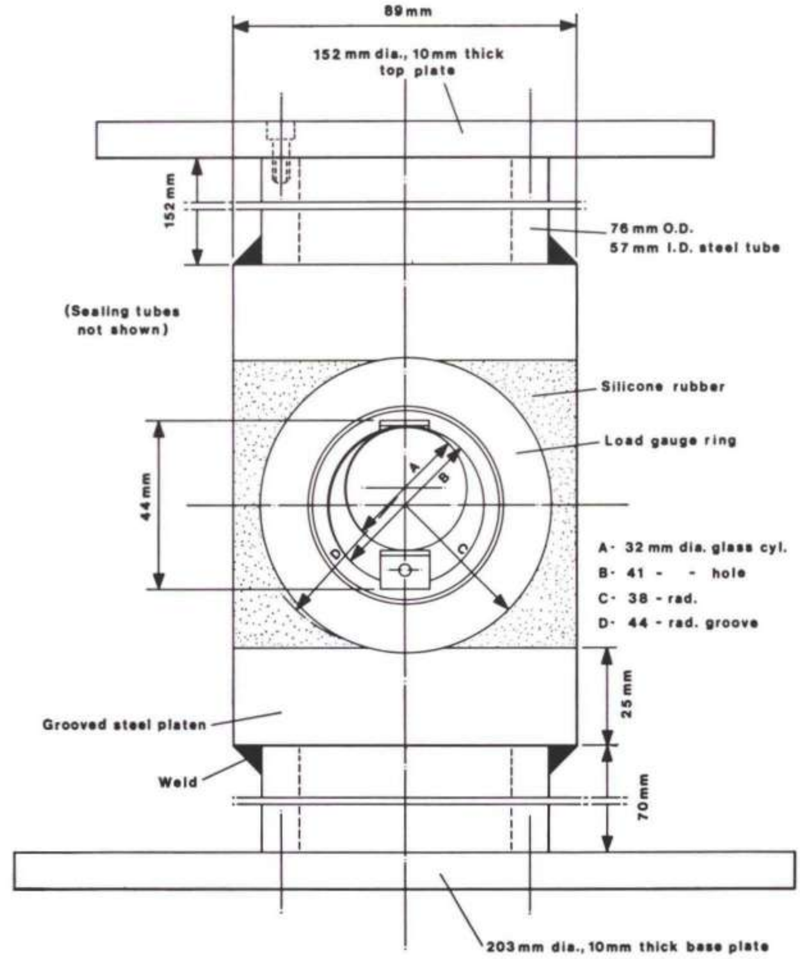

Fig. 10

Details of 100 kN load gauge for earth pressure cell

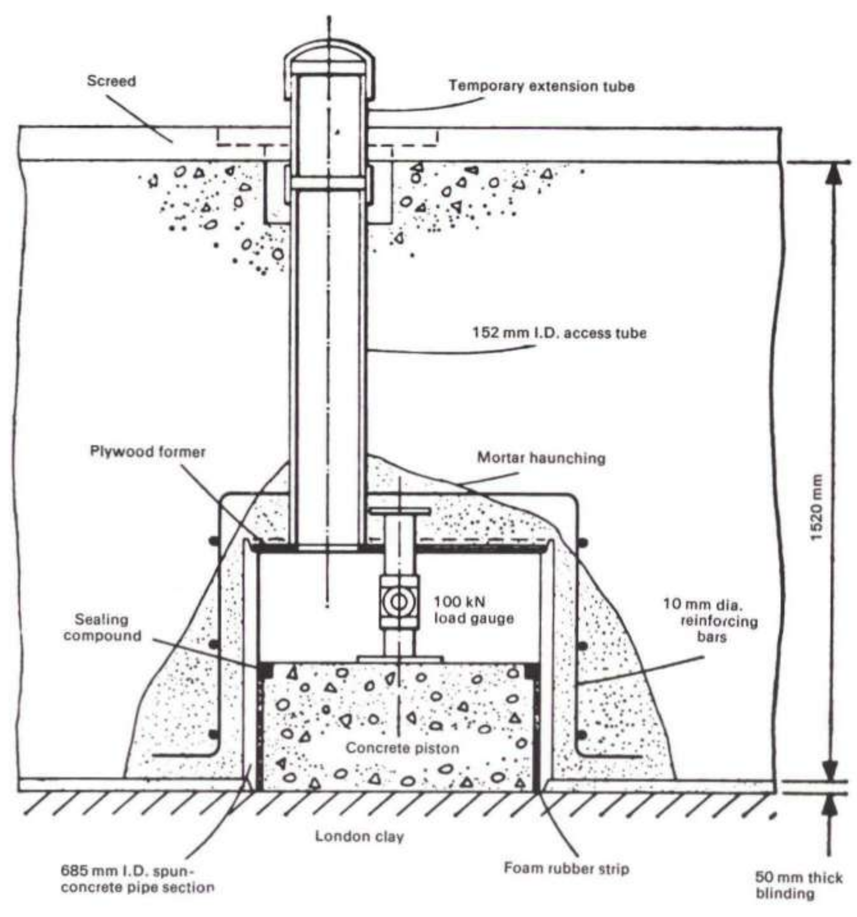

Fig. 11

Arrangement of earth pressure cell

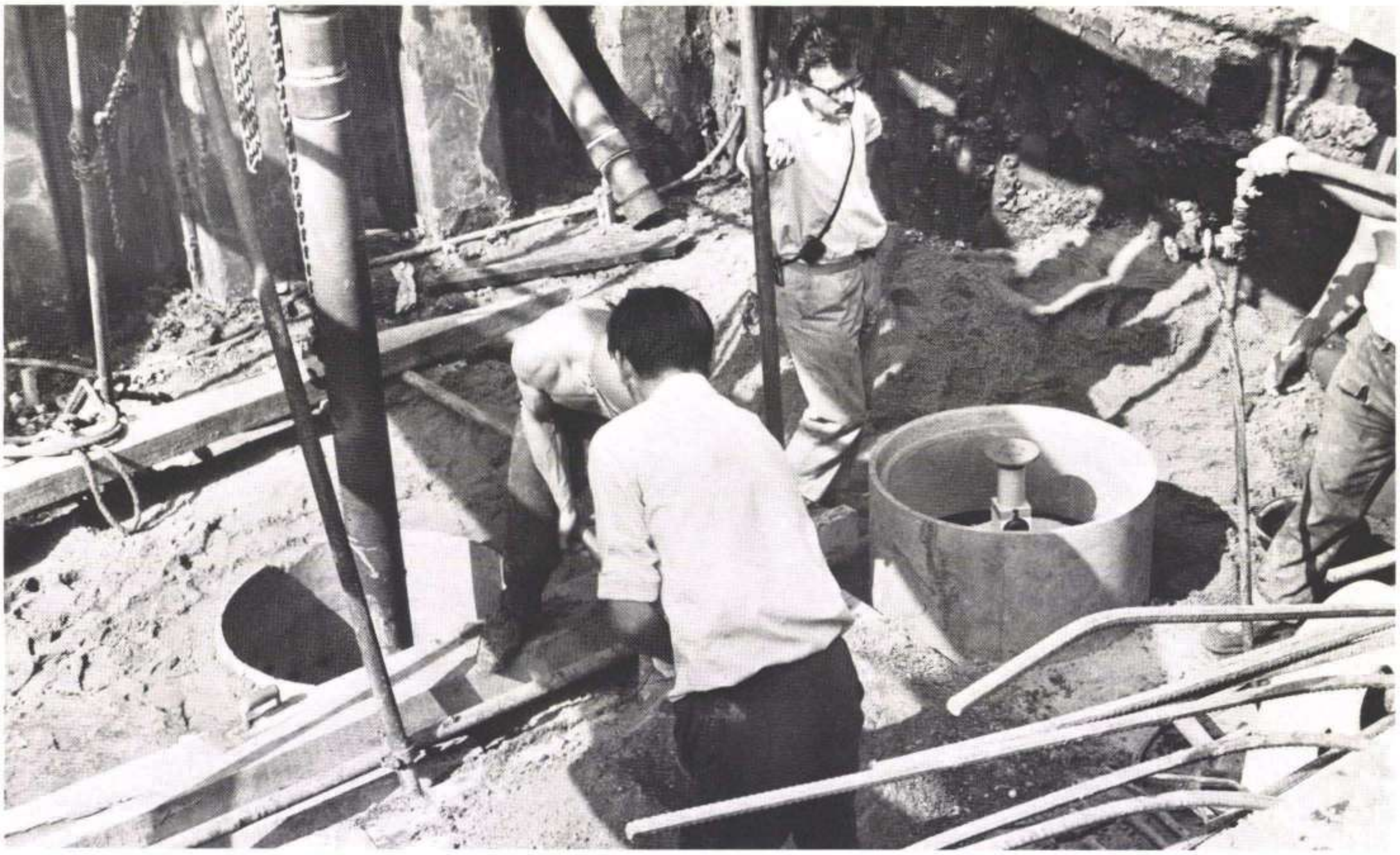

Fig. 12

Site installation of earth pressure cell and pile load cell

grooved steel platens which are welded onto the ends of two lengths of thick-walled steel tubing. The circular end plates are fixed to the tubes by screwed connections to ensure accurate alignment and also to permit the removal of the upper plate during installation. The ring gauge and loading platens are held in position with silicone rubber (*Silcoset 105* paste, curing agent *A*). As protection against corrosion, the entire surface area of the load gauge ring was chromium plated, as were the inner surfaces of the grooved loading platens. An epoxy resin paint was applied to the external surfaces of all remaining steel components with the exception of the outer surfaces of the end plates, which were coated with red-lead paint.

Construction and installation of earth pressure cells

The form of construction of the earth pressure cell is shown in Fig. 11. After carefully levelling the clay surface and removing all loose material, a 610 mm wide section of 685 mm diameter spun concrete pipe was placed on the prepared surface. A sheet of foam rubber (305 mm wide, 13 mm thick) was positioned around the inner surface of the pipe section, and concrete poured to give a 305 mm thick piston. After the concrete had set, a sealing compound (*Expandite* heavy-duty sealer) was poured into a specially prepared recess formed around the top of the piston. The load gauge unit was then placed on a thin bed of mortar at the centre of the piston, and a plywood former passed over the upper gauge column to rest on top of the concrete pipe section. The load gauge end plate was screwed onto its column, and the 152 mm diameter access tube positioned on the wooden template. A protective cover of mortar reinforced with steel bars was placed around the cell, and the raft concreting completed some days later.

The situation on site during installation of an earth pressure cell is illustrated in Fig. 12; also shown is the vertical access tube of an adjacent pile load cell. The portable polarized light unit described earlier is used in taking earth pressure cell readings.

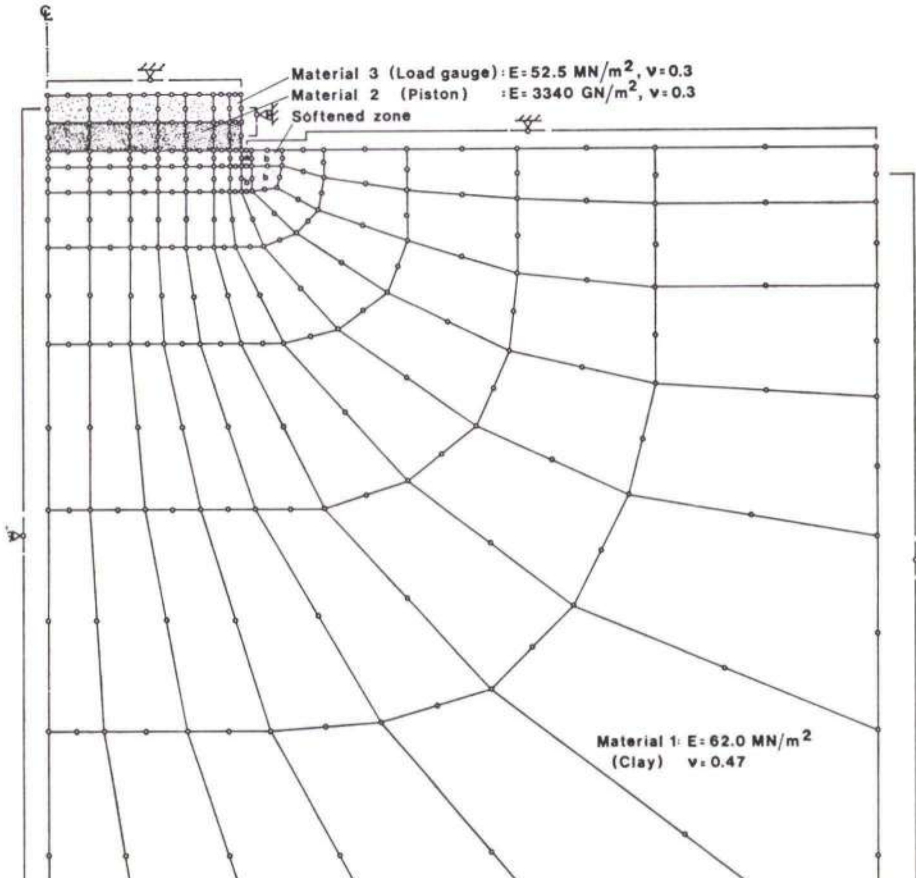

Fig. 13

Mathematical model for analysis

Effect of cell stiffness on measured contact pressures

An important consideration in the design of any type of earth pressure cell is the effect of the presence of the cell itself on measured pressures. In the present case, for example, inward movement of the concrete piston will give rise to an indicated pressure which is lower than the corresponding pressure existing on the base of a continuous raft. The extent of this reduction in contact pressure depends upon the diameter and stiffness of the cell, and upon the stress-strain behaviour of the soil.

As a result of an extensive investigation into pressure measurements in sand carried out at the US Waterways Experiment Station[6], a number of general guidelines were given regarding overall cell design. For cells mounted flush at a rigid surface, experiments showed that the effect of cell compressibility on indicated pressures was negligible provided that the ratio of cell diameter to normal deflection of the pressure face exceeded 1000. In a subsequent theoretical analysis based on the experimental data, Taylor[7] estimated that at this ratio, a cell would under-register by approximately 9 per cent. However, these conclusions strictly relate only to a particular set of test conditions; they are not directly applicable, for example, to pressure measurements in clay soils.

In order to provide more definite results for the present case, the effect of piston movement on indicated pressures was investigated by means of the finite element method. The mathematical model employed in the analysis is shown in Fig. 13. The elements themselves are isoparametric quadrilaterals (87 elements, 298 nodes) in their axisymmetric form[8], and allow a parabolic variation in displacement between corner nodes. The boundary constraints are also indicated in Fig. 13; the singularity at the re-entrant corner was dealt with by restricting displacement of the corner node in the horizontal direction only, thus allowing free vertical movement of the piston.

The elastic constants assumed for the soil (material 1) are consistent with typical values for London Clay at shallow depths. The elastic constants for the model piston (material 2) result directly from the known bending stiffness of the concrete piston; likewise, those for material 3 are derived from the measured load-displacement response of the load gauge unit.

The resulting distribution of normal contact pressure across the face of the piston due to a uniform pressure applied at the free clay surface is shown in Fig. 14. Here $\xi = x/R$, where x is measured horizontally from the centre-line and R denotes the radius of the piston. The curve labelled 'elastic' corresponds to the case where a constant value of Young's modulus is assigned to the entire mass of clay, whereas the curve labelled 'pseudo-elastic' relates to the case where the Young's modulus of the clay in close proximity to the edge of the piston is reduced to simulate the localized plastic flow which undoubtedly occurs in practice. In this latter analysis, the elastic moduli of elements *a* and *b* (Fig. 13) were reduced to 10 per cent and 25 per cent of their initial values respectively.

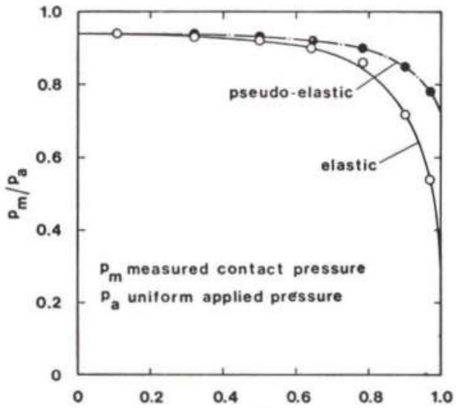

Fig. 14

Distribution of normal contact pressure across face of piston

Based on the data given in Fig. 14, average values of the ratio of measured pressure to applied pressure (p_m/p_a) are 0.87 for the 'elastic' case and 0.91 for the 'pseudo-elastic' case. In practice, it is reasonable to take the latter value for the purposes of correcting measured earth pressures.

Conclusions

Both the pile load cells and the earth pressure cells have functioned satisfactorily over a period of several years, and have yielded useful data on the behaviour of piled rafts in clay.

Only the sealing arrangements were inadequate, and this led to groundwater penetrating each of the cells. But apart from the inconvenience of having to pump the cells dry prior to taking readings, the state of near-permanent submergence appears to have had no adverse effect on the performance of the load gauges. Relatively minor modifications would be required in order to ensure water-tightness of any future cells of this type.

Satisfactory performance of the load gauges during the present investigation has demonstrated the suitability of this form of instrumentation for long-term field measurements. On the basis of this experience, pile load cells of similar design have recently been installed in another piled-raft foundation.

Acknowledgements

The development of the instrumentation referred to above was carried out at the former Postgraduate School of Mining, Sheffield University, with the aid of a grant from the Science Research Council. The cost of manufacturing and installing the load cells was met by the Department of the Environment.

The pile load cells were calibrated using the testing facilities at the Building Research Establishment. The finite element analysis of the earth pressure cell problem was carried out in conjunction with Mr D. J. Naylor of the University College of Swansea, South Wales.

The support of Mr L. R. Creasy, OBE, and Mr R. P. Haines, OBE, of the Department of the Environment is gratefully acknowledged. Thanks are also due to the architect, Sir Basil Spence, OM, RA, and the main contractor, Sir Robert McAlpine and Sons Ltd. for their willing co-operation, and to Mr F. G. Butler and Mr D. O. Jordan of Ove Arup and Partners for their help at the design stage. The load gauge components were manufactured to the author's design and specification by Stress Engineering Services Ltd., Midsomer Norton, Somerset.

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New bridge at St. Katharine's Dock

The inner lifting bridge at St. Katharine's is a road bridge crossing the entrance lock. The lifting ropes are operated by hydraulic rams lying in trenches beside the bridge approaches. The Tower Hotel is on the left. The bridge was designed by the Civil Engineering Division, and built by Boulton & Paul Ltd. M & E Services: Mole-Richardson Ltd.

Above: the bridge closed Below: the bridge open (Photos: Harry Sowden)

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